ECOSYSTEMS AND HUMAN WELL-BEING

OUR HUMAN PLANET

Summary for Decision Makers

MILLENNIUM ECOSYSTEM ASSESSMENT

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Our Human Planet: Summary for Decision-makers

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Millennium Ecosystem Assessment

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Millennium Ecosystem Assessment: Objectives, Focus, and Approach

The Millennium Ecosystem Assessment was carried out between 2001 and 2005 to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The MA responds to government requests for information received through four international conventions—the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species—and is designed to also meet needs of other stakeholders, including the business community, the health sector, nongovernmental organizations, and indigenous peoples. The sub-global assessments also aimed to meet the needs of users in the regions where they were undertaken.

The assessment focuses on the linkages between ecosystems and human well-being and, in particular, on "ecosystem services." An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. The MA deals with the full range of ecosystems—from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use and to ecosystems intensively managed and modified by humans, such as agricultural land and urban areas. Ecosystem services are the benefits people obtain from ecosystems. These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services.

The MA examines how changes in ecosystem services influence human well-being. Human well-being is assumed to have multiple constituents, including the *basic material for a good life*, such as secure and adequate livelihoods, enough food at all times, shelter, clothing, and access to goods; *health*, including feeling well and having a healthy physical environment, such as clean air and access to clean water; *good social relations*, including social cohesion, mutual respect, and the ability to help others and provide for children; *security*, including secure access to natural and other resources, personal safety, and security from natural and human-made disasters; and *freedom of choice and action*, including the opportunity to achieve what an individual values doing and being. Freedom of choice and action is influenced by other constituents of well-being (as well as by other factors, notably education) and is also a precondition for achieving other components of well-being, particularly with respect to equity and fairness.

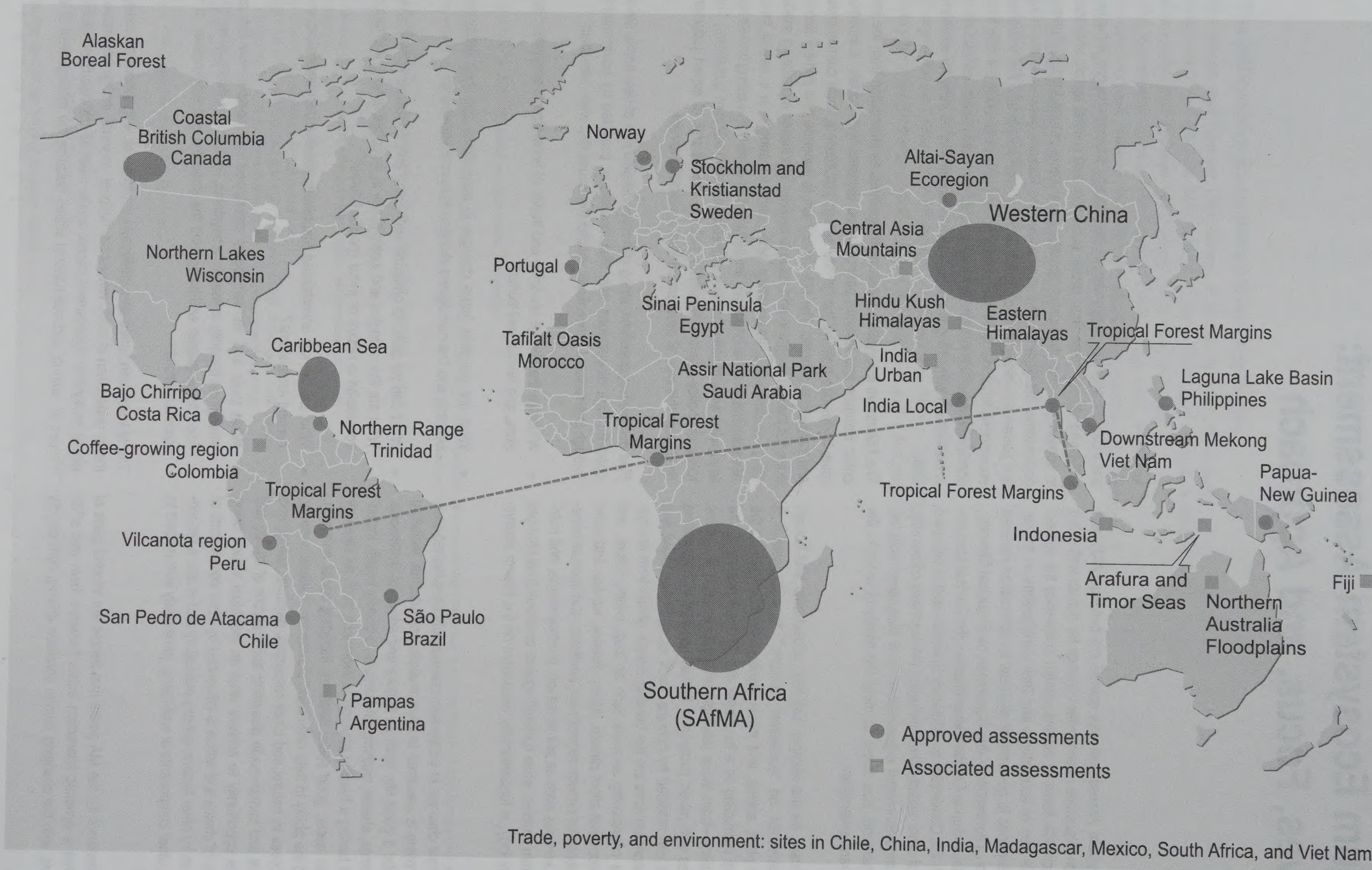
The conceptual framework for the MA posits that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being. At the same time, social, economic, and cultural factors unrelated to ecosystems alter the human condition, and many natural forces influence ecosystems. Although the MA emphasizes the linkages between ecosystems and human well-being, it recognizes that the actions people take that influence ecosystems result not just from concern about human well-being but also from considerations of the intrinsic value of species and ecosystems. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else.

The Millennium Ecosystem Assessment synthesizes information from the scientific literature and relevant peer-reviewed datasets and models. It incorporates knowledge held by the private sector, practitioners, local communities, and indigenous peoples. The MA did not aim to generate new primary knowledge but instead sought to add value to existing information by collating, evaluating, summarizing, interpreting, and communicating it in a useful form. Assessments like this one apply the judgment of experts to existing knowledge to provide scientifically credible answers to policy-relevant questions. The focus on policy-relevant questions and the explicit use of expert judgment distinguish this type of assessment from a scientific review.

Five overarching questions, along with more detailed lists of user needs developed through discussions with stakeholders or provided by governments through international conventions, guided the issues that were assessed:

- What are the current condition and trends of ecosystems, ecosystem services, and human well-being?
- What are plausible future changes in ecosystems and their ecosystem services and the consequent changes in human well-being?
- What can be done to enhance well-being and conserve ecosystems? What are the strengths and weaknesses of response options that can be considered to realize or avoid specific futures?
- What are the key uncertainties that hinder effective decision-making concerning ecosystems?
- What tools and methodologies developed and used in the MA can strengthen capacity to assess ecosystems, the services they provide, their impacts on human well-being, and the strengths and weaknesses of response options?

The MA was conducted as a multiscale assessment, with interlinked assessments undertaken at local, watershed, national, regional, and global scales. A global ecosystem assessment cannot easily meet all the needs of decision-makers at national and sub-national scales because the management of any



Eighteen assessments were approved as components of the MA. Any institution or country was able to undertake an assessment as part of the MA if it agreed to use the MA conceptual framework, to centrally involve the intended users as stakeholders and partners, and to meet a set of procedural requirements related to peer review, metadata, transparency, and intellectual property rights. The MA assessments were largely self-funded, although planning grants and some core grants were provided to support some assessments. The MA also drew on information from 16 other sub-global assessments affiliated with the MA that met a subset of these criteria or were at earlier stages in development.

	ECOSYSTEM TYPES										ECOSYSTEM SERVICES								
SUB-GLOBAL ASSESSMENT	COASTAL	CULTIVATED	DRYLAND	FOREST	INLAND WATER	ISLAND	MARINE	MOUNTAIN	POLAR	URBAN	FOOD	WATER	FUEL and ENERGY	BIODIVERSITY-RELATED	CARBON SEQUESTRATION	FIBER and TIMBER	RUNOFF REGULATION	CULTURAL, SPIRITUAL, AMENITY	OTHERS
Altai-Sayan Ecoregion			●	●	●			●			●		●	●		●		●	
San Pedro de Atacama, Chile			●		●						●	●		●			●	●	●
Caribbean Sea	●					●	●				●	●		●				●	
Coastal British Columbia, Canada	●			●	●			●			●			●		●	●	●	
Bajo Chirripo, Costa Rica		●		●	●						●	●		●		●		●	●
Tropical Forest Margins		●		●							●	●		●	●	●	●		●
India Local Villages		●		●	●						●	●	●	●		●	●	●	●
Glomma Basin, Norway		●		●	●			●			●		●			●		●	●
Papua New Guinea	●	●				●	●				●	●	●	●		●	●	●	●
Vilcanota, Peru		●	●					●			●	●		●			●	●	●
Laguna Lake Basin, Philippines		●		●	●						●	●		●	●			●	●
Portugal	●	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●
São Paulo Green Belt, Brazil	●	●		●	●					●	●	●		●	●	●	●	●	●
Southern Africa	●	●	●	●	●					●	●	●	●	●		●		●	●
Stockholm and Kristianstad, Sweden		●			●					●	●	●		●	●	●	●	●	●
Northern Range, Trinidad	●			●	●			●			●	●		●		●	●	●	●
Downstream Mekong Wetlands, Viet Nam	●	●			●						●	●	●	●	●	●	●	●	●
Western China		●	●	●	●			●			●	●		●	●		●		●
Alaskan Boreal Forest				●	●						●					●		●	●
Arafura and Timor Seas	●					●	●				●			●	●				●
Argentine Pampas		●									●	●						●	●
Central Asia Mountains								●			●	●		●					●
Colombia coffee-growing regions		●						●			●	●		●				●	
Eastern Himalayas				●				●			●	●	●	●				●	
Sinai Peninsula, Egypt			●					●						●			●	●	●
Fiji	●					●					●	●	●						●
Hindu Kush-Himalayas					●			●				●		●			●	●	●
Indonesia	●					●	●				●			●					●
India Urban Resource										●	●	●	●	●	●			●	●
Tafilalt Oasis, Morocco		●	●								●	●						●	●
Northern Australia Floodplains					●						●	●		●			●	●	●
Assir National Park, Saudi Arabia		●		●				●			●						●	●	●
Northern Highlands Lake District, Wisconsin				●	●							●				●	●	●	●

particular ecosystem must be tailored to the particular characteristics of that ecosystem and to the demands placed on it. However, an assessment focused only on a particular ecosystem or particular nation is insufficient because some processes are global and because local goods, services, matter, and energy are often transferred across regions. Each of the component assessments was guided by the MA conceptual framework and benefited from the presence of assessments undertaken at larger and smaller scales. The sub-global assessments were not intended to serve as representative samples of all ecosystems; rather, they were to meet the needs of decision-makers at the scales at which they were undertaken. The sub-global assessments involved in the MA process are shown in the Figure and the ecosystems and ecosystem services examined in these assessments are shown in the Table.

The work of the MA was conducted through four working groups, each of which prepared a report of its findings. At the global scale, the Condition and Trends Working Group assessed the state of knowledge on ecosystems, drivers of ecosystem change, ecosystem services, and associated human well-being around the year 2000. The assessment aimed to be comprehensive with regard to ecosystem services, but its coverage is not exhaustive. The Scenarios Working Group considered the possible evolution of ecosystem services during the twenty-first century by developing four global scenarios exploring plausible future changes in drivers, ecosystems, ecosystem services, and human well-being. The Responses Working Group examined the strengths and weaknesses of various response options that have been used to manage ecosystem services and identified promising opportunities for improving human well-being while conserving ecosystems. The report of the Sub-global Assessments Working Group contains lessons learned from the MA sub-global assessments. The first product of the MA—*Ecosystems and Human Well-being: A Framework for Assessment,* published in 2003—outlined the focus, conceptual basis, and methods used in the MA. The executive summary of this publication appears as Chapter 1 of this volume.

Approximately 1,360 experts from 95 countries were involved as authors of the assessment reports, as participants in the sub-global assessments, or as members of the Board of Review Editors. The latter group, which involved 80 experts, oversaw the scientific review of the MA reports by governments and experts and ensured that all review comments were appropriately addressed by the authors. All MA findings underwent two rounds of expert and governmental review. Review comments were received from approximately 850 individuals (of which roughly 250 were submitted by authors of other chapters in the MA), although in a number of cases (particularly in the case of governments and MA-affiliated scientific organizations), people submitted collated comments that had been prepared by a number of reviewers in their governments or institutions.

The MA was guided by a Board that included representatives of five international conventions, five U.N. agencies, international scientific organizations, governments, and leaders from the private sector, nongovernmental organizations, and indigenous groups. A 15-member Assessment Panel of leading social and natural scientists oversaw the technical work of the assessment, supported by a secretariat with offices in Europe, North America, South America, Asia, and Africa and coordinated by the United Nations Environment Programme.

The MA is intended to be used:

- to identify priorities for action;
- as a benchmark for future assessments;
- as a framework and source of tools for assessment, planning, and management;
- to gain foresight concerning the consequences of decisions affecting ecosystems;
- to identify response options to achieve human development and sustainability goals;
- to help build individual and institutional capacity to undertake integrated ecosystem assessments and act on the findings; and
- to guide future research.

Because of the broad scope of the MA and the complexity of the interactions between social and natural systems, it proved to be difficult to provide definitive information for some of the issues addressed in the MA. Relatively few ecosystem services have been the focus of research and monitoring and, as a consequence, research findings and data are often inadequate for a detailed global assessment. Moreover, the data and information that are available are generally related to either the characteristics of the ecological system or the characteristics of the social system, not to the all-important interactions between these systems. Finally, the scientific and assessment tools and models available to undertake a cross-scale integrated assessment and to project future changes in ecosystem services are only now being developed. Despite these challenges, the MA was able to provide considerable information relevant to most of the focal questions. And by identifying gaps in data and information that prevent policy-relevant questions from being answered, the assessment can help to guide research and monitoring that may allow those questions to be answered in future assessments.

Contents

Foreword

The Millennium Ecosystem Assessment (MA) was called for by United Nations Secretary-General Kofi Annan in 2000 in his report to the UN General Assembly, *We the Peoples: The Role of the United Nations in the 21st Century.* Governments subsequently supported the establishment of the assessment through decisions taken by three international conventions (the Convention on Biodiversity, the Convention to Combat Desertification, and the Ramsar Convention on Wetlands), and the MA was initiated in 2001. The Convention on Migratory Species subsequently associated with the assessment. The MA was conducted under the auspices of the United Nations, with the secretariat coordinated by the United Nations Environment Programme, and it was governed by a multistakeholder board that included representatives of international institutions, governments, business, nongovernmental organizations, and indigenous peoples. The objective of the MA was to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being.

The MA comprises four assessment reports (*Current State and Trends, Scenarios, Policy Responses,* and *Multiscale Assessments*) and six synthesis reports (one for a general audience and others focused on issues of biodiversity, wetlands and water, desertification, health, and business and ecosystems). The synthesis reports were prepared for decision-makers in these different sectors, and they integrate findings from across all the working groups for ease of use by those audiences.

This volume contains the Summary for Decision-makers from the four assessment reports prepared by the following groups: the Condition and Trends Working Group, which assessed the state of knowledge on ecosystems and their services, drivers of ecosystem change, and the consequences of ecosystem change for human well-being; the Scenarios Working Group, which examined possible changes in ecosystem services during the twenty-first century by developing four global scenarios exploring plausible future changes in drivers, ecosystems, ecosystem services, and human well-being; the Responses Working Group, which examined the strengths and weaknesses of various response options that have been used to manage ecosystem services and identified promising opportunities for improving human well-being while conserving ecosystems; and the Sub-global Assessments Working Group, which summarized lessons learned from the local, watershed, national, and regional assessments that were undertaken as part of the MA process. The material in this report has undergone extensive peer review by experts and governments, overseen by an independent Board of Review Editors.

The MA provides a unique foundation of knowledge concerning human dependence on ecosystems as we enter the twenty-first century. Never before has such a holistic assessment been conducted that addresses multiple environmental changes, multiple drivers, and multiple linkages to human well-being, as well as ways in which societies have sought to manage those linkages. Collectively, these reports reveal both the extraordinary success that humanity has achieved in shaping ecosystems to meet the needs of growing populations and economies and the growing costs associated with many of these changes. They show us that these costs could grow substantially in the future, but also that there are actions within reach that could dramatically enhance both human well-being and the conservation of ecosystems.

This report would not have been possible without the extraordinary commitment of more than 2,000 authors and reviewers worldwide who contributed their knowledge, creativity, time, and enthusiasm to the development of the assessment, and we wish to acknowledge the in-kind support of their institutions, which enabled their participation.

We want to express our gratitude to the members of the MA Board, Board alternates, Exploratory Steering Committee, Assessment Panel, coordinating lead authors, lead authors, contributing authors, Board of Review Editors, and expert reviewers for their extraordinary contributions to this process.

We would particularly like to thank the co-chairs of the Condition and Trends Working Group, Dr. Rashid Hassan and Dr. Robert Scholes, and the Technical Support Unit Coordinator, Neville Ash; the co-chairs of the Scenarios Working Group, Dr. Stephen Carpenter and Dr. Prabhu Pingali, and the TSU Coordinators, Dr. Elena Bennett and Dr. Monika Zurek; the co-chairs of the Responses Working Group, Dr. Kanchan Chopra and Dr. Rik Leemans, and the TSU Coordinators, Pushpam Kumar and Henk Simons; and the co-chairs of the Sub-global Assessments Working Group, Dr. Doris Capistrano and Dr. Cristián Samper, and the TSU Coordinators, Marcus Lee and Ciara Raudsepp-Hearne, for their skillful leadership of their working groups and their contributions to the overall assessment.

We would like to thank the host organizations of the MA Technical Support Units—WorldFish Center (Malaysia); UNEP-World Conservation Monitoring Centre

(United Kingdom); Institute of Economic Growth (India); National Institute of Public Health and the Environment (Netherlands); University of Pretoria (South Africa), U.N. Food and Agriculture Organization (Italy); World Resources Institute, Meridian Institute, and Center for Limnology of the University of Wisconsin (all in the United States); Scientific Committee on Problems of the Environment (France); and International Maize and Wheat Improvement Center (Mexico)—for the support they provided to the process. The Scenarios Working Group was established as a joint project of the MA and the Scientific Committee on Problems of the Environment, and we thank SCOPE for the scientific input and oversight that it provided.

We are also extremely grateful to the donors that provided major financial support for the MA: Global Environment Facility; United Nations Foundation; David and Lucile Packard Foundation; World Bank; Consultative Group on International Agricultural Research; United Nations Environment Programme; Government of China; Ministry of Foreign Affairs of the Government of Norway; Kingdom of Saudi Arabia; and Swedish International Biodiversity Programme. The full list of organizations that provided financial support to the MA is available at www.MAweb.org.

We give special thanks for the full-time staff of the MA Secretariat: Chan Wai Leng, John Ehrmann, Lori Han, Christine Jalleh, Marcus Lee, Belinda Lim, Nicolas Lucas, Mampiti Matete, Tasha Merican, Meenakshi Rathore, Ciara Raudsepp-Hearne, Sara Suriani, Jillian Thonell, and Valerie Thompson. This volume contains summaries that appeared in reports that were skillfully edited by Rosemarie Philips and Linda Starke. We also thank the interns and volunteers who worked with the MA Secretariat, part-time members of the Secretariat staff, the administrative staff of the host organizations, and colleagues in other organizations who were instrumental in facilitating the process.

Finally, we would particularly like to thank Angela Cropper and Harold Mooney, the co-chairs of the MA Assessment Panel, and José Sarukhán and Anne Whyte, the co-chairs of the MA Review Board, for their skillful leadership of the assessment and review processes, and Walter Reid, the MA Director, for his pivotal role in establishing the assessment, his leadership, and his outstanding contributions to the process.

Dr. Robert T. Watson
MA Board Co-chair
Chief Scientist, The World Bank

Dr. A.H. Zakri
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Director, Institute for Advanced Studies,
United Nations University

Reader's Guide

Four technical reports present the findings of each of the MA Working Groups: Condition and Trends, Scenarios, Responses, and Sub-global Assessments. This volume, *Our Human Planet*, presents the summaries of all four reports in order to offer a concise account of the technical reports for decision-makers. In addition, six synthesis reports were prepared for ease of use by specific audiences: Synthesis (general audience), CBD (biodiversity), UNCCD (desertification), Ramsar Convention (wetlands), business and industry, and the health sector. Each MA sub-global assessment will also produce additional reports to meet the needs of its own audiences.

All printed materials of the assessment, along with core data and a list of reviewers, are available at www.MAweb.org.

Throughout this volume, dollar signs indicate U.S. dollars and ton means tonne (metric ton). Bracketed references are to chapters within each technical volume.

The following words have been used where appropriate to indicate judgmental estimates of certainty, based on the collective judgment of the authors, using the observational evidence, modeling results, and theory that they have examined: very certain (98% or greater probability), high certainty (85–98% probability), medium certainty (65%–58% probability), low certainty (52–65% probability), and very uncertain (50–52% probability). In other instances, a qualitative scale to gauge the level of scientific understanding is used: well established, established but incomplete, competing explanations, and speculative. Each time these terms are used they appear in italics.

Chapter 1

MA Conceptual Framework

BOXES

FIGURES

This chapter provides the summary of Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: A Framework for Assessment* (Island Press, 2003), pp. 1–25, which was prepared by an extended conceptual framework writing team of 51 authors and 10 contributing authors.

Main Messages

Human well-being and progress toward sustainable development are vitally dependent upon improving the management of Earth's ecosystems to ensure their conservation and sustainable use. But while demands for ecosystem services such as food and clean water are growing, human actions are at the same time diminishing the capability of many ecosystems to meet these demands.

Sound policy and management interventions can often reverse ecosystem degradation and enhance the contributions of ecosystems to human well-being, but knowing when and how to intervene requires substantial understanding of both the ecological and the social systems involved. Better information cannot guarantee improved decisions, but it is a prerequisite for sound decision-making.

The Millennium Ecosystem Assessment was established to help provide the knowledge base for improved decisions and to build capacity for analyzing and supplying this information.

This chapter presents the conceptual and methodological approach that the MA used to assess options that can enhance the contribution of ecosystems to human well-being. This same approach should provide a suitable basis for governments, the private sector, and civil society to factor considerations of ecosystems and ecosystem services into their own planning and actions.

1.1 Introduction

Humanity has always depended on the services provided by the biosphere and its ecosystems. Further, the biosphere is itself the product of life on Earth. The composition of the atmosphere and soil, the cycling of elements through air and waterways, and many other ecological assets are all the result of living processes—and all are maintained and replenished by living ecosystems. The human species, while buffered against environmental immediacies by culture and technology, is ultimately fully dependent on the flow of ecosystem services.

In his April 2000 Millennium Report to the United Nations General Assembly, in recognition of the growing burden that degraded ecosystems are placing on human well-being and economic development and the opportunity that better managed ecosystems provide for meeting the goals of poverty eradication and sustainable development, United Nations Secretary-General Kofi Annan stated that:

> *It is impossible to devise effective environmental policy unless it is based on sound scientific information. While major advances in data collection have been made in many areas, large gaps in our knowledge remain. In particular, there has never been a comprehensive global assessment of the world's major ecosystems. The planned Millennium Ecosystem Assessment, a major international collaborative effort to map the health of our planet, is a response to this need.*

The Millennium Ecosystem Assessment was established with the involvement of governments, the private sector, nongovernmental organizations, and scientists to provide an integrated assessment of the consequences of ecosystem change for human well-being and to analyze options available to enhance the conservation of ecosystems and their contributions to meeting human needs. The Convention on Biological Diversity, the Convention to Combat Desertification, the Convention on Migratory Species, and the Ramsar Convention on Wetlands plan to use the findings of the MA, which will also help meet the needs of others in government, the private sector, and civil society. The MA should help to achieve the United Nations Millennium Development Goals and to carry out the Plan of Implementation of the 2002 World Summit on Sustainable Development. It has mobilized hundreds of scientists from countries around the world to provide information and clarify science concerning issues of greatest relevance to decision-makers. The MA has identified areas of broad scientific agreement and also pointed to areas of continuing scientific debate.

The assessment framework developed for the MA offers decision-makers a mechanism to:

- ***Identify options that can better achieve core human development and sustainability goals. All countries and communities are grappling with the challenge of meeting growing demands for food, clean water, health, and employment.*** And decision-makers in the private and public sectors must also balance economic growth and social development with the need for environmental conservation. All of these concerns are linked directly or indirectly to the world's ecosystems. The MA process, at all scales, was designed to bring the best science to bear on the needs of decision-makers concerning these links between ecosystems, human development, and sustainability.
- ***Better understand the trade-offs involved—across sectors and stakeholders—in decisions concerning the environment.*** Ecosystem-related problems have historically been approached issue by issue, but rarely by pursuing multisectoral objectives. This approach has not withstood the test of time. Progress toward one objective such as increasing food production has often been at the cost of progress toward other objectives such as conserving biological diversity or improving water quality. The MA framework complements sectoral assessments with information on the full impact of potential policy choices across sectors and stakeholders.
- ***Align response options with the level of governance where they can be most effective.*** Effective management of ecosystems will require actions at all scales, from the local to the global. Human actions now directly or inadvertently affect virtually all of the world's ecosystems; actions required for the management of ecosystems refer to the steps that humans can take to modify their direct or indirect influences on ecosystems. The management and policy options available and the concerns of stakeholders differ greatly across these scales. The priority areas for biodiversity conservation in a country as defined based on "global" value, for example, would be very different from those as defined based on the value to local communities. The multiscale assessment framework developed for the MA provides a new approach for analyzing

policy options at all scales—from local communities to international conventions.

1.2 What Is the Problem?

Ecosystem services are the benefits people obtain from ecosystems, which the MA describes as provisioning, regulating, supporting, and cultural services. (See Box 1.1.) Ecosystem services include products such as food, fuel, and fiber; regulating services such as climate regulation and disease control; and nonmaterial benefits such as spiritual or aesthetic benefits. Changes in these services affect human well-being in many ways. (See Figure 1.1.)

The demand for ecosystem services is now so great that trade-offs among services have become the rule. A country can increase food supply by converting a forest to agriculture, for example, but in so doing it decreases the supply of services that may be of equal or greater importance, such as clean water, timber, ecotourism destinations, or flood regulation and drought control. There are many indications that human demands on ecosystems will grow still greater in the coming decades. Current estimates of 3 billion more people and a quadrupling of the world economy by 2050 imply a formidable increase in demand for and consumption of biological and physical resources, as well as escalating impacts on ecosystems and the services they provide.

The problem posed by the growing demand for ecosystem services is compounded by increasingly serious degradation in the capability of ecosystems to provide these services. World fisheries are now declining due to overfishing, for instance, and a significant amount of agricultural land has been degraded in the past half-century by erosion, salinization, compaction, nutrient depletion, pollution, and urbanization. Other human-induced impacts on ecosystems include alteration of the nitrogen, phosphorous, sulfur, and carbon cycles, causing acid rain, algal blooms, and fish kills in rivers and coastal waters, along with contributions to climate change. In many parts of the world, this degradation of ecosystem services is exacerbated by the associated loss of the knowledge and understanding held by local communities—knowledge that sometimes could help to ensure the sustainable use of the ecosystem.

This combination of ever-growing demands being placed on increasingly degraded ecosystems seriously diminishes the prospects for sustainable development. Human well-being is affected not just by gaps between ecosystem service supply and demand but also by the increased vulnerability of individuals, communities, and nations. Productive ecosystems, with their array of services, provide people and communities with resources and options they can use as insurance in the face of natural catastrophes or social upheaval. While well-managed ecosystems reduce risks and vulnerability, poorly managed systems can exacerbate them by increasing risks of flood, drought, crop failure, or disease.

Ecosystem degradation tends to harm rural populations more directly than urban populations and has its most direct and severe impact on poor people. The wealthy control access to a greater share of ecosystem services, consume those services at a higher per capita rate, and are buffered from changes in their availability (often at a substantial cost) through their ability to purchase scarce ecosystem services or substitutes. For example, even though a number of marine fisheries have been depleted in the past century, the supply of fish to wealthy consumers has not been disrupted since fishing fleets have been able to shift to previously underexploited stocks. In contrast, poor people often lack access to alternate services and are highly vulnerable to ecosystem changes that result in famine, drought, or floods. They frequently live in locations particularly sensitive to environmental threats, and they lack financial and institutional buffers against these dangers. Degradation of coastal fishery resources, for instance, results in a decline in protein consumed by the local community since fishers may not have access to alternate sources of fish and community members may not have enough income to purchase fish. Degradation affects their very survival.

Changes in ecosystems affect not just humans but countless other species as well. The management objectives that people set for ecosystems and the actions that they take are influenced not just by the consequences of ecosystem changes for humans but also by the importance people place on considerations of the intrinsic value of species and ecosystems. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else. For example, villages in India protect "spirit sanctuaries" in relatively natural states, even though a strict cost-benefit calculation might favor their conversion to agriculture. Similarly, many countries have passed laws protecting endangered species based on the view that these species have a right to exist, even if their protection results in net economic costs. Sound ecosystem management thus involves steps to address the utilitarian links of people to ecosystems as well as processes that allow considerations of the intrinsic value of ecosystems to be factored into decision-making.

BOX 1.1
Key Definitions

Ecosystem. An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. Humans are an integral part of ecosystems. Ecosystems vary enormously in size; a temporary pond in a tree hollow and an ocean basin can both be ecosystems.

Ecosystem services. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits.

Well-being. Human well-being has multiple constituents, including basic material for a good life, freedom of choice and action, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, which has been defined as a "pronounced deprivation in well-being." The constituents of well-being, as experienced and perceived by people, are situation-dependent, reflecting local geography, culture, and ecological circumstances.

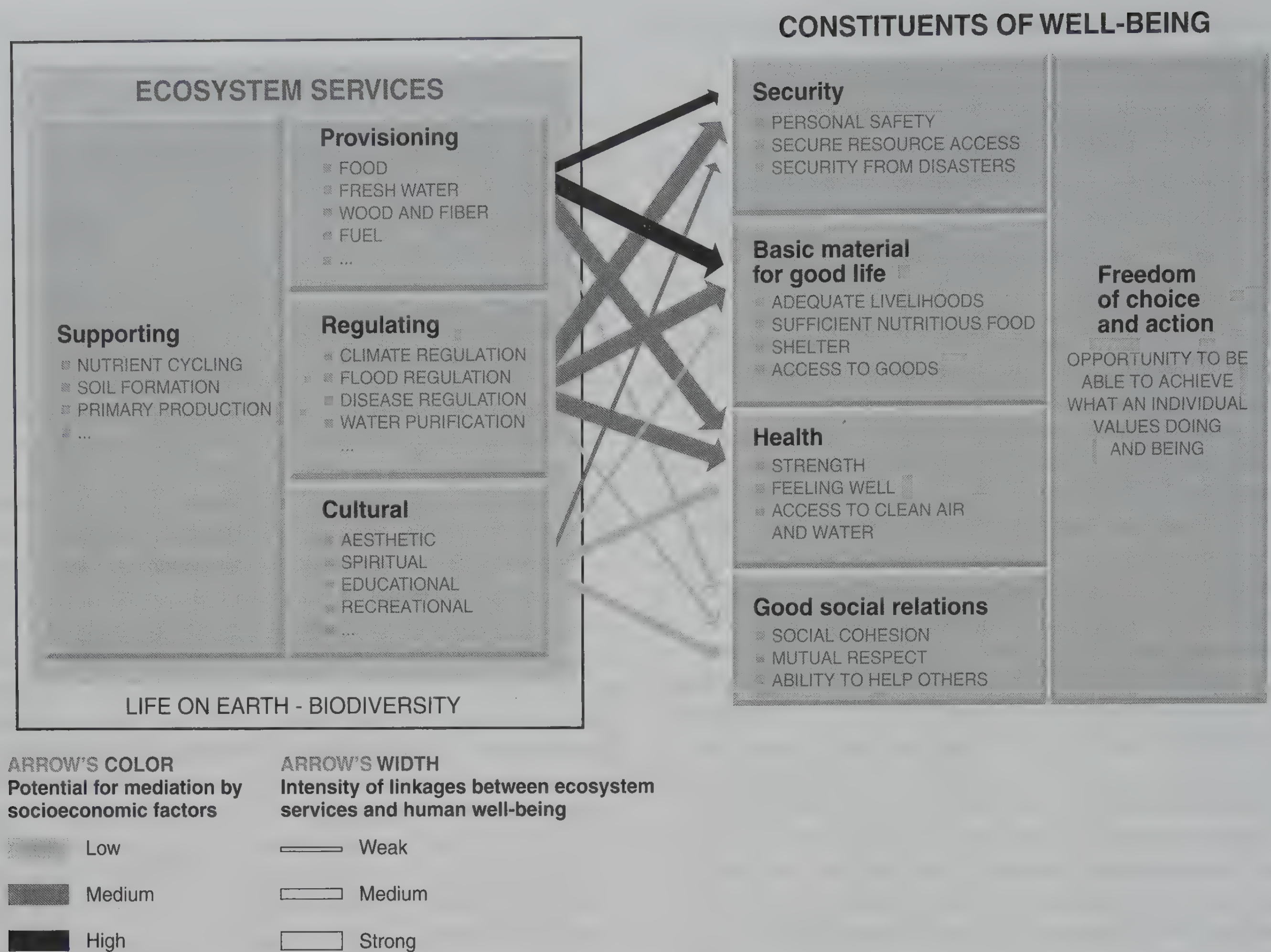


Figure 1.1. Linkages between Ecosystem Services and Human Well-being. This Figure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. (For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation.) The strength of the linkages and the potential for mediation differ in different ecosystems and regions. In addition to the influence of ecosystem services on human well-being depicted here, other factors—including other environmental factors as well as economic, social, technological, and cultural factors—influence human well-being, and ecosystems are in turn affected by changes in human well-being.

The degradation of ecosystem services has many causes, including excessive demand for ecosystem services stemming from economic growth, demographic changes, and individual choices. Market mechanisms do not always ensure the conservation of ecosystem services either because markets do not exist for services such as cultural or regulatory services or, where they do exist, because policies and institutions do not enable people living within the ecosystem to benefit from services it may provide to others who are far away. For example, institutions are now only beginning to be developed to enable those benefiting from carbon sequestration to provide local managers with an economic incentive to leave a forest uncut, while strong economic incentives often exist for managers to harvest the forest. Also, even if a market exists for an ecosystem service, the results obtained through the market may be socially or ecologically undesirable. Properly managed, the creation of ecotourism opportunities in a country can create strong economic incentives for the maintenance of the cultural services provided by ecosystems, but poorly managed ecotourism activities can degrade the very resource on which they depend. Finally, markets are often unable to address important intra- and intergenerational equity issues associated with managing ecosystems for this and future generations, given that some changes in ecosystem services are irreversible.

The world has witnessed in recent decades not just dramatic changes to ecosystems but equally profound changes to social systems that shape both the pressures on ecosystems and the opportunities to respond. The relative influence of individual nation-states has diminished with the growth of power and influence of a far more complex array of institutions, including regional governments, multinational companies, the United Nations, and civil society organizations. Stakeholders have become more involved in decision-making. Given the multiple actors whose decisions now strongly influence ecosystems, the challenge of providing information to decision-makers has grown. At the same

time, the new institutional landscape may provide an unprecedented opportunity for information concerning ecosystems to make a major difference. Improvements in ecosystem management to enhance human well-being will require new institutional and policy arrangements and changes in rights and access to resources that may be more possible today under these conditions of rapid social change than they have ever been before.

Like the benefits of increased education or improved governance, the protection, restoration, and enhancement of ecosystem services tends to have multiple and synergistic benefits. Already, many governments are beginning to recognize the need for more effective management of these basic life-support systems. Examples of significant progress toward sustainable management of biological resources can also be found in civil society, in indigenous and local communities, and in the private sector.

1.3 Conceptual Framework

The conceptual framework for the MA places human well-being as the central focus for assessment, while recognizing that biodiversity and ecosystems also have intrinsic value and that people take decisions concerning ecosystems based on considerations of well-being as well as intrinsic value. (See Box 1.2.) The MA conceptual framework assumes that a dynamic interaction exists between people and other parts of ecosystems, with the changing human condition serving to both directly and indirectly drive change in ecosystems and with changes in ecosystems causing changes in human well-being. At the same time, many other factors independent of the environment change the human condition, and many natural forces are influencing ecosystems.

The MA focuses particular attention on the linkages between ecosystem services and human well-being. The assessment deals with the full range of ecosystems—from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use and ecosystems intensively managed and modified by humans, such as agricultural land and urban areas.

A full assessment of the interactions between people and ecosystems requires a multiscale approach because it better reflects the multiscale nature of decision-making, allows the examination of driving forces that may be exogenous to particular regions, and provides a means of examining the differential impact of ecosystem changes and policy responses on different regions and groups within regions.

This section explains in greater detail the characteristics of each of the components of the MA conceptual framework, moving clockwise from the lower left corner of the Figure in Box 1.2.

1.3.1 Ecosystems and Their Services

An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. Humans are an integral part of ecosystems. Ecosystems provide a variety of benefits to people, including provisioning, regulating, cultural, and supporting services. Provisioning services are the products people obtain from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources. Regulating services are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification. Cultural services are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Supporting services are those that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation.

Biodiversity and ecosystems are closely related concepts. Biodiversity is the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. It includes diversity within and between species and diversity of ecosystems. Diversity is a structural feature of ecosystems, and the variability among ecosystems is an element of biodiversity. Products of biodiversity include many of the services produced by ecosystems (such as food and genetic resources), and changes in biodiversity can influence all the other services they provide. In addition to the important role of biodiversity in providing ecosystem services, the diversity of living species has intrinsic value independent of any human concern.

The concept of an ecosystem provides a valuable framework for analyzing and acting on the linkages between people and the environment. For that reason, the "ecosystem approach" has been endorsed by the Convention on Biological Diversity, and the MA conceptual framework is entirely consistent with this approach. The CBD states that the ecosystem approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. This approach recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

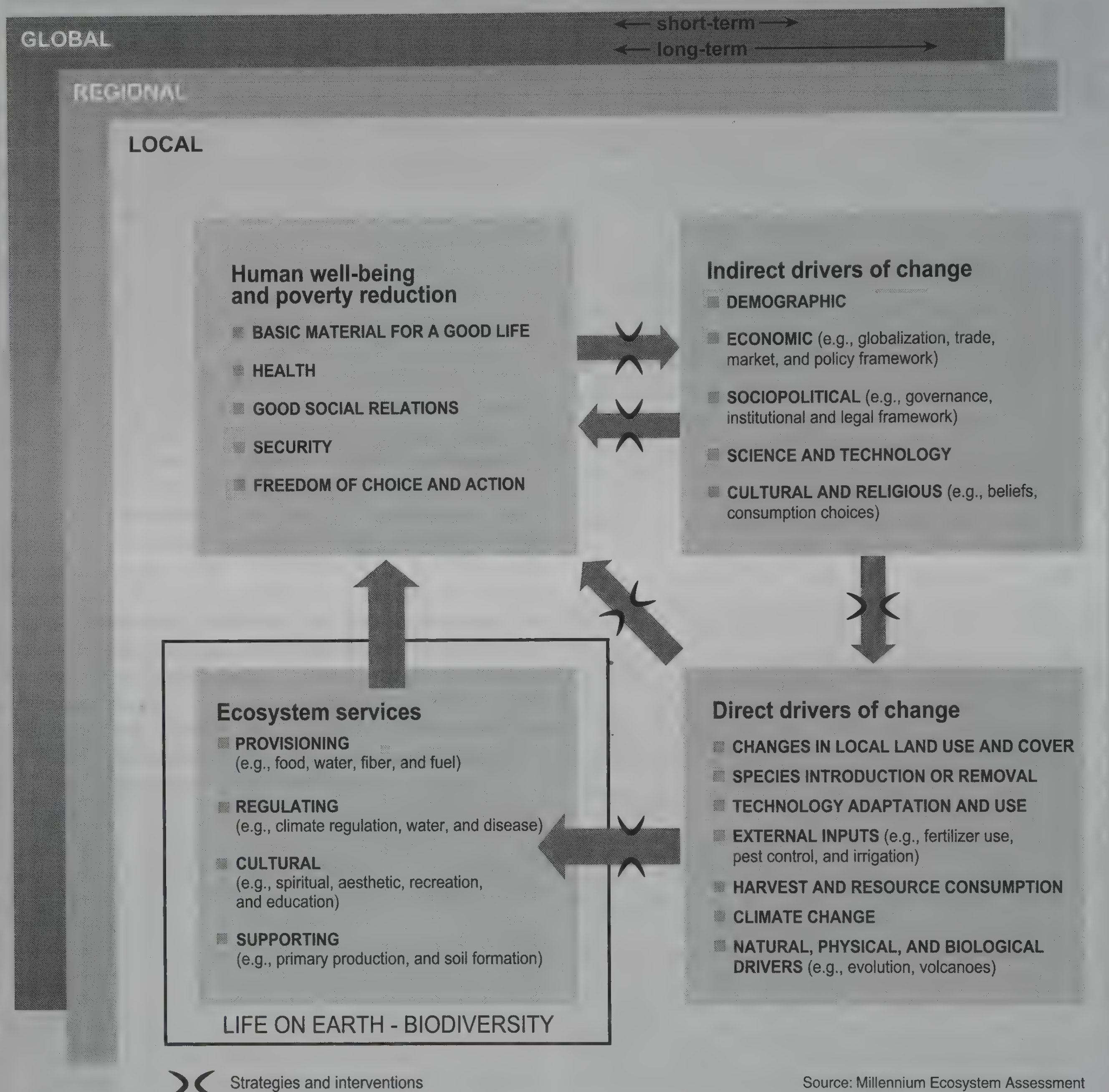
In order to implement the ecosystem approach, decision-makers need to understand the multiple effects on an ecosystem of any management or policy change. By way of analogy, decision-makers would not make a decision about financial policy in a country without examining the condition of the economic system, since information on the economy of a single sector such as manufacturing would be insufficient. The same need to examine the consequences of changes for multiple sectors applies to ecosystems. For instance, subsidies for fertilizer use may increase food production, but sound decisions also require information on whether the potential reduction in the harvests of downstream fisheries as a result of water quality degradation from the fertilizer runoff might outweigh those benefits.

For the purpose of analysis and assessment, a pragmatic view of ecosystem boundaries must be adopted, depending on the questions being asked. A well-defined ecosystem has strong interactions among its components and weak interactions across its boundaries. A useful choice of ecosystem boundary is one where a number of discontinuities coincide, such as in the distribution of organisms, soil types,

BOX 1.2

Millennium Ecosystem Assessment Conceptual Framework

Changes in factors that indirectly affect ecosystems, such as population, technology, and lifestyle (upper right corner of figure), can lead to changes in factors directly affecting ecosystems, such as the catch of fisheries or the application of fertilizers to increase food production (lower right corner). The resulting changes in the ecosystem (lower left corner) cause the ecosystem services to change and thereby affect human well-being. These interactions can take place at more than one scale and can cross scales. For example, a global market may lead to regional loss of forest cover, which increases flood magnitude along a local stretch of a river. Similarly, the interactions can take place across different time scales. Actions can be taken either to respond to negative changes or to enhance positive changes at almost all points in this framework (black cross bars).



drainage basins, and depth in a waterbody. At a larger scale, regional and even globally distributed ecosystems can be evaluated based on a commonality of basic structural units. The global assessment being undertaken by the MA reports on marine, coastal, inland water, forest, dryland, island, mountain, polar, cultivated, and urban regions. These regions are not ecosystems themselves, but each contains a number of ecosystems. (See Box 1.3.)

People seek multiple services from ecosystems and thus perceive the condition of given ecosystems in relation to their ability to provide the services desired. Various methods can be used to assess the ability of ecosystems to deliver

BOX 1.3

Reporting Categories Used in the Millennium Ecosystem Assessment

The MA used 10 categories of systems to report its global findings. (See Table.) These categories are not ecosystems themselves; each contains a number of ecosystems. The MA reporting categories are not mutually exclusive: their areas can and do overlap. Ecosystems within each category share a suite of biological, climatic, and social factors that tend to differ across categories. Because these reporting categories overlap, any place on Earth may fall into more than one category. Thus, for example, a wetland ecosystem in a coastal region may be examined both in the MA analysis of "coastal systems" as well as in its analysis of "inland water systems."

Millennium Ecosystem Assessment Reporting Categories

Category	Central Concept	Boundary Limits for Mapping
Marine	Ocean, with fishing typically a major driver of change	Marine areas where the sea is deeper than 50 meters.
Coastal	Interface between ocean and land, extending seawards to about the middle of the continental shelf and inland to include all areas strongly influenced by the proximity to the ocean	Area between 50 meters below mean sea level and 50 meters above the high tide level or extending landward to a distance 100 kilometers from shore. Includes coral reefs, intertidal zones, estuaries, coastal aquaculture, and seagrass communities.
Inland water	Permanent water bodies inland from the coastal zone, and areas whose ecology and use are dominated by the permanent, seasonal, or intermittent occurrence of flooded conditions	Rivers, lakes, floodplains, reservoirs, and wetlands; includes inland saline systems. Note that the Ramsar Convention considers "wetlands" to include both inland water and coastal categories.
Forest	Lands dominated by trees; often used for timber, fuelwood, and non-timber forest products	A canopy cover of at least 40% by woody plants taller than 5 meters. The existence of many other definitions is acknowledged, and other limits (such as crown cover greater than 10%, as used by the Food and Agriculture Organization of the United Nations) are also reported. Includes temporarily cut-over forests and plantations; excludes orchards and agroforests where the main products are food crops.
Dryland	Lands where plant production is limited by water availability; the dominant uses are large mammal herbivory, including livestock grazing, and cultivation	Drylands as defined by the Convention to Combat Desertification, namely lands where annual precipitation is less than two thirds of potential evaporation, from dry subhumid areas (ratio ranges 0.50–0.65), through semiarid, arid, and hyper-arid (ratio $<$0.05), but excluding polar areas; drylands include cultivated lands, scrublands, shrublands, grasslands, semi-deserts, and true deserts.
Island	Lands isolated by surrounding water, with a high proportion of coast to hinterland	Islands of at least 1.5 hectares included in the ESRI ArcWorld Country Boundary dataset.
Mountain	Steep and high lands	As defined by Mountain Watch using criteria based on elevation alone, and at lower elevation, on a combination of elevation, slope, and local elevation range. Specifically, elevation $>$2,500 meters, elevation 1,500–2,500 meters and slope $>$2 degrees, elevation 1,000–1,500 meters and slope $>$5 degrees or local elevation range (7 kilometers radius) $>$300 meters, elevation 300–1,000 meters and local elevation range (7 kilometers radius) $>$300 meters, isolated inner basins and plateaus less than 25 square kilometers extent that are surrounded by mountains.
Polar	High-latitude systems frozen for most of the year	Includes ice caps, areas underlain by permafrost, tundra, polar deserts, and polar coastal areas. Excludes high-altitude cold systems in low latitudes.
Cultivated	Lands dominated by domesticated plant species, used for and substantially changed by crop, agroforestry, or aquaculture production	Areas in which at least 30% of the landscape comes under cultivation in any particular year. Includes orchards, agroforestry, and integrated agriculture-aquaculture systems.
Urban	Built environments with a high human density	Known human settlements with a population of 5,000 or more, with boundaries delineated by observing persistent night-time lights or by inferring areal extent in the cases where such observations are absent.

particular services. With those answers in hand, stakeholders have the information they need to decide on a mix of services best meeting their needs. The MA considers criteria and methods to provide an integrated view of the condition of ecosystems. The condition of each category of ecosystem services is evaluated in somewhat different ways, although in general a full assessment of any service requires considerations of stocks, flows, and resilience of the service.

1.3.2 Human Well-being and Poverty Reduction

Human well-being has multiple constituents, including the basic material for a good life, freedom of choice and action, health, good social relations, and security. Poverty is also multidimensional and has been defined as the pronounced deprivation of well-being. How well-being, ill-being, or poverty are experienced and expressed depends on context and situation, reflecting local physical, social, and personal factors such as geography, environment, age, gender, and culture. In all contexts, however, ecosystems are essential for human well-being through their provisioning, regulating, cultural, and supporting services.

Human intervention in ecosystems can amplify the benefits to human society. However, evidence in recent decades of escalating human impacts on ecological systems worldwide raises concerns about the spatial and temporal consequences of ecosystem changes detrimental to human well-being. Ecosystem changes affect human well-being in the following ways:

- ***Security*** is affected both by changes in provisioning services, which affect supplies of food and other goods and the likelihood of conflict over declining resources, and by changes in regulating services, which could influence the frequency and magnitude of floods, droughts, landslides, or other catastrophes. It can also be affected by changes in cultural services as, for example, when the loss of important ceremonial or spiritual attributes of ecosystems contributes to the weakening of social relations in a community. These changes in turn affect material well-being, health, freedom and choice, security, and good social relations.
- ***Access to basic material for a good life*** is strongly linked to both provisioning services such as food and fiber production and regulating services, including water purification.
- ***Health*** is strongly linked to both provisioning services such as food production and regulating services, including those that influence the distribution of disease-transmitting insects and of irritants and pathogens in water and air. Health can also be linked to cultural services through recreational and spiritual benefits.
- ***Social relations*** are affected by changes to cultural services, which affect the quality of human experience.
- ***Freedom of choice and action*** is largely predicated on the existence of the other components of well-being and are thus influenced by changes in provisioning, regulating, or cultural services from ecosystems.

Human well-being can be enhanced through sustainable human interactions with ecosystems supported by necessary instruments, institutions, organizations, and technology. Creation of these through participation and transparency may contribute to freedoms and choice as well as to increased economic, social, and ecological security. By ecological security, we mean the minimum level of ecological stock needed to ensure a sustainable flow of ecosystem services.

Yet the benefits conferred by institutions and technology are neither automatic nor equally shared. In particular, such opportunities are more readily grasped by richer than poorer countries and people; some institutions and technologies mask or exacerbate environmental problems; responsible governance, while essential, is not easily achieved; participation in decision-making, an essential element of responsible governance, is expensive in time and resources to maintain. Unequal access to ecosystem services has often elevated the well-being of small segments of the population at the expense of others.

Sometimes the consequences of the depletion and degradation of ecosystem services can be mitigated by the substitution of knowledge and of manufactured or human capital. For example, the addition of fertilizer in agricultural systems has been able to offset declining soil fertility in many regions of the world where people have sufficient economic resources to purchase these inputs, and water treatment facilities can sometimes substitute for the role of watersheds and wetlands in water purification. But ecosystems are complex and dynamic systems and there are limits to substitution possibilities, especially with regulating, cultural, and supporting services. No substitution is possible for the extinction of culturally important species such as tigers or whales, for instance, and substitutions may be economically impractical for the loss of services such as erosion control or climate regulation. Moreover, the scope for substitutions varies by social, economic, and cultural conditions. For some people, especially the poorest, substitutes and choices are very limited. For those who are better off, substitution may be possible through trade, investment, and technology.

Because of the inertia in both ecological and human systems, the consequences of ecosystem changes made today may not be felt for decades. Thus, sustaining ecosystem services, and thereby human well-being, requires a full understanding and wise management of the relationships between human activities, ecosystem change, and well-being over the short, medium, and long term. Excessive current use of ecosystem services compromises their future availability. This can be prevented by ensuring that the use is sustainable.

Achieving sustainable use requires effective and efficient institutions that can provide the mechanisms through which concepts of freedom, justice, fairness, basic capabilities, and equity govern the access to and use of ecosystem services. Such institutions may also need to mediate conflicts between individual and social interests that arise.

The best way to manage ecosystems to enhance human well-being will differ if the focus is on meeting needs of the poor and weak or the rich and powerful. For both groups, ensuring the long-term supply of ecosystem services is es-

sential. But for the poor, an equally critical need is to provide more equitable and secure access to ecosystem services.

1.3.3 Drivers of Change

Understanding the factors that cause changes in ecosystems and ecosystem services is essential to designing interventions that capture positive impacts and minimize negative ones. In the MA, a "driver" is any factor that changes an aspect of an ecosystem. A direct driver unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy. An indirect driver operates more diffusely, often by altering one or more direct drivers, and its influence is established by understanding its effect on a direct driver. Both indirect and direct drivers often operate synergistically. Changes in land cover, for example, can increase the likelihood of introduction of alien invasive species. Similarly, technological advances can increase rates of economic growth.

The MA explicitly recognizes the role of decision-makers who affect ecosystems, ecosystem services, and human well-being. Decisions are made at three organizational levels, although the distinction between those levels is often diffuse and difficult to define:

- by individuals and small groups at the local level (such as a field or forest stand) who directly alter some part of the ecosystem;
- by public and private decision-makers at the municipal, provincial, and national levels; and
- by public and private decision-makers at the international level, such as through international conventions and multilateral agreements.

The decision-making process is complex and multidimensional. We refer to a driver that can be influenced by a decision-maker as an endogenous driver and one over which the decision-maker does not have control as an exogenous driver. The amount of fertilizer applied on a farm is an endogenous driver from the standpoint of the farmer, for example, while the price of the fertilizer is an exogenous driver, since the farmer's decisions have little direct influence on price. The specific temporal, spatial, and organizational scale dependencies of endogenous and exogenous drivers and the specific linkages and interactions among drivers are assessed in the MA.

Whether a driver is exogenous or endogenous to a decision-maker is dependent upon the spatial and temporal scale. For example, a local decision-maker can directly influence the choice of technology, changes in land use, and external inputs (such as fertilizers or irrigation), but has little control over prices and markets, property rights, technology development, or the local climate. In contrast, a national or regional decision-maker has more control over many factors, such as macroeconomic policy, technology development, property rights, trade barriers, prices, and markets. But on the short time scale, that individual has little control over the climate or global population. On the longer time scale, drivers that are exogenous to a decision-maker in the short run, such as population, become endogenous since the decision-maker can influence them through, for instance, education, the advancement of women, and migration policies.

The indirect drivers of change are primarily:

- demographic (such as population size, age and gender structure, and spatial distribution);
- economic (such as national and per capita income, macroeconomic policies, international trade, and capital flows);
- sociopolitical (such as democratization, the roles of women, of civil society, and of the private sector, and international dispute mechanisms);
- scientific and technological (such as rates of investments in research and development and the rates of adoption of new technologies, including biotechnologies and information technologies); and
- cultural and religious (such as choices individuals make about what and how much to consume and what they value).

The interaction of several of these drivers, in turn, affects levels of resource consumption and differences in consumption both within and between countries. Clearly these drivers are changing—population and the world economy are growing, for instance, there are major advances in information technology and biotechnology, and the world is becoming more interconnected. Changes in these drivers are projected to increase the demand for and consumption of food, fiber, clean water, and energy, which will in turn affect the direct drivers. The direct drivers are primarily physical, chemical, and biological—such as land cover change, climate change, air and water pollution, irrigation, use of fertilizers, harvesting, and the introduction of alien invasive species. Change is apparent here too: the climate is changing, species ranges are shifting, alien species are spreading, and land degradation continues.

An important point is that any decision can have consequences external to the decision framework. These consequences are called externalities because they are not part of the decision-making calculus. Externalities can have positive or negative effects. For example, a decision to subsidize fertilizers to increase crop production might result in substantial degradation of water quality from the added nutrients and degradation of downstream fisheries. But it is also possible to have positive externalities. A beekeeper might be motivated by the profits to be made from selling honey, for instance, but neighboring orchards could produce more apples because of enhanced pollination arising from the presence of the bees.

Multiple interacting drivers cause changes in ecosystem services. There are functional interdependencies between and among the indirect and direct drivers of change, and, in turn, changes in ecological services lead to feedbacks on the drivers of changes in ecological services. Synergetic driver combinations are common. The many processes of globalization lead to new forms of interactions between drivers of changes in ecosystem services.

1.3.4 Cross-scale Interactions and Assessment

An effective assessment of ecosystems and human well-being cannot be conducted at a single temporal or spatial

scale. Thus the MA conceptual framework includes both of these dimensions. Ecosystem changes that may have little impact on human well-being over days or weeks (soil erosion, for instance) may have pronounced impacts over years or decades (declining agricultural productivity). Similarly, changes at a local scale may have little impact on some services at that scale (as in the local impact of forest loss on water availability) but major impacts at large scales (forest loss in a river basin changing the timing and magnitude of downstream flooding).

Ecosystem processes and services are typically most strongly expressed, are most easily observed, or have their dominant controls or consequences at particular spatial and temporal scales. They often exhibit a characteristic scale—the typical extent or duration over which processes have their impact. Spatial and temporal scales are often closely related. For instance, food production is a localized service of an ecosystem and changes on a weekly basis, water regulation is regional and changes on a monthly or seasonal basis, and climate regulation may take place at a global scale over decades.

Assessments need to be conducted at spatial and temporal scales appropriate to the process or phenomenon being examined. Those done over large areas generally use data at coarse resolutions, which may not detect fine-resolution processes. Even if data are collected at a fine level of detail, the process of averaging in order to present findings at the larger scale causes local patterns or anomalies to disappear. This is particularly problematic for processes exhibiting thresholds and nonlinearities. For example, even though a number of fish stocks exploited in a particular area might have collapsed due to overfishing, average catches across all stocks (including healthier stocks) would not reveal the extent of the problem. Assessors, if they are aware of such thresholds and have access to high-resolution data, can incorporate such information even in a large-scale assessment. Yet an assessment done at smaller spatial scales can help identify important dynamics of the system that might otherwise be overlooked. Likewise, phenomena and processes that occur at much larger scales, although expressed locally, may go unnoticed in purely local-scale assessments. Increased carbon dioxide concentrations or decreased stratospheric ozone concentrations have local effects, for instance, but it would be difficult to trace the causality of the effects without an examination of the overall global process.

Time scale is also very important in conducting assessments. Humans tend not to think beyond one or two generations. If an assessment covers a shorter time period than the characteristic temporal scale, it may not adequately capture variability associated with long-term cycles, such as glaciation. Slow changes are often harder to measure, as is the case with the impact of climate change on the geographic distribution of species or populations. Moreover, both ecological and human systems have substantial inertia, and the impact of changes occurring today may not be seen for years or decades. For example, some fisheries' catches may increase for several years even after they have reached unsustainable levels because of the large number of juvenile fish produced before that level was reached.

Social, political, and economic processes also have characteristic scales, which may vary widely in duration and extent. Those of ecological and sociopolitical processes often do not match. Many environmental problems originate from this mismatch between the scale at which the ecological process occurs, the scale at which decisions are made, and the scale of institutions for decision-making. A purely local-scale assessment, for instance, may discover that the most effective societal response requires action that can occur only at a national scale (such as the removal of a subsidy or the establishment of a regulation). Moreover, it may lack the relevance and credibility necessary to stimulate and inform national or regional changes. On the other hand, a purely global assessment may lack both the relevance and the credibility necessary to lead to changes in ecosystem management at the local scale where action is needed. Outcomes at a given scale are often heavily influenced by interactions of ecological, socioeconomic, and political factors emanating from other scales. Thus focusing solely on a single scale is likely to miss interactions with other scales that are critically important in understanding ecosystem determinants and their implications for human well-being.

The choice of the spatial or temporal scale for an assessment is politically laden, since it may intentionally or unintentionally privilege certain groups. The selection of assessment scale with its associated level of detail implicitly favors particular systems of knowledge, types of information, and modes of expression over others. For example, non-codified information or knowledge systems of minority populations are often missed when assessments are undertaken at larger spatial scales or higher levels of aggregation. Reflecting on the political consequences of scale and boundary choices is an important prerequisite to exploring what multi- and cross-scale analysis in the MA might contribute to decision-making and public policy processes at various scales.

1.4 Values Associated with Ecosystems

Current decision-making processes often ignore or underestimate the value of ecosystem services. Decision-making concerning ecosystems and their services can be particularly challenging because different disciplines, philosophical views, and schools of thought assess the value of ecosystems differently. One paradigm of value, known as the utilitarian (anthropocentric) concept, is based on the principle of humans' preference satisfaction (welfare). In this case, ecosystems and the services they provide have value to human societies because people derive utility from their use, either directly or indirectly (use values). Within this utilitarian concept of value, people also give value to ecosystem services that they are not currently using (non-use values). Non-use values, usually known as existence values, involve the case where humans ascribe value to knowing that a resource exists even if they never use that resource directly. These often involve the deeply held historical, national, ethical, religious, and spiritual values people ascribe to ecosystems—the values that the MA recognizes as cultural services of ecosystems.

A different, non-utilitarian value paradigm holds that something can have intrinsic value—that is, it can be of value in and for itself—irrespective of its utility for someone else. From the perspective of many ethical, religious, and cultural points of view, ecosystems may have intrinsic value, independent of their contribution to human well-being.

The utilitarian and non-utilitarian value paradigms overlap and interact in many ways, but they use different metrics, with no common denominator, and cannot usually be aggregated, although both paradigms of value are used in decision-making processes.

Under the utilitarian approach, a wide range of methodologies has been developed to attempt to quantify the benefits of different ecosystem services. These methods are particularly well developed for provisioning services, but recent work has also improved the ability to value regulating and other services. The choice of valuation technique in any given instance is dictated by the characteristics of the case and by data availability. (See Box 1.4.)

Non-utilitarian value proceeds from a variety of ethical, cultural, religious, and philosophical bases. These differ in the specific entities that are deemed to have intrinsic value and in the interpretation of what having intrinsic value means. Intrinsic value may complement or counterbalance considerations of utilitarian value. For example, if the aggregate utility of the services provided by an ecosystem (as measured by its utilitarian value) outweighs the value of converting it to another use, its intrinsic value may then be complementary and provide an additional impetus for conserving the ecosystem. If, however, economic valuation indicates that the value of converting the ecosystem outweighs the aggregate value of its services, its ascribed intrinsic value may be deemed great enough to warrant a social decision to conserve it anyway. Such decisions are essentially political, not economic. In contemporary democracies these decisions are made by parliaments or legislatures or by regulatory agencies mandated to do so by law. The sanctions for violating laws recognizing an entity's intrinsic value may be regarded as a measure of the degree of intrinsic value ascribed to them. The decisions taken by businesses, local communities, and individuals also can involve considerations of both utilitarian and non-utilitarian values.

The mere act of quantifying the value of ecosystem services cannot by itself change the incentives affecting their use or misuse. Several changes in current practice may be required to take better account of these values. The MA assesses the use of information on ecosystem service values in decision-making. The goal is to improve decision-making processes and tools and to provide feedback regarding the kinds of information that can have the most influence.

BOX 1.4

Valuation of Ecosystem Services

Valuation can be used in many ways: to assess the total contribution that ecosystems make to human well-being, to understand the incentives that individual decision-makers face in managing ecosystems in different ways, and to evaluate the consequences of alternative courses of action. The MA uses valuation primarily in the latter sense: as a tool that enhances the ability of decision-makers to evaluate trade-offs between alternative ecosystem management regimes and courses of social actions that alter the use of ecosystems and the multiple services they provide. This usually requires assessing the change in the mix (the value) of services provided by an ecosystem resulting from a given change in its management.

Most of the work involved in estimating the change in the value of the flow of benefits provided by an ecosystem involves estimating the change in the physical flow of benefits (quantifying biophysical relations) and tracing through and quantifying a chain of causality between changes in ecosystem condition and human welfare. A common problem in valuation is that information is only available on some of the links in the chain and often in incompatible units. The MA can make a major contribution by making various disciplines better aware of what is needed to ensure that their work can be combined with that of others to allow a full assessment of the consequences of altering ecosystem state and function.

The ecosystem values in this sense are only one of the bases on which decisions on ecosystem management are and should be made. Many other factors, including notions of intrinsic value and other objectives that society might have (such as equity among different groups or generations), will also feed into the decision framework. Even when decisions are made on other bases, however, estimates of changes in utilitarian value provide invaluable information.

1.5 Assessment Tools

The information base exists in any country to undertake an assessment within the framework of the MA. That said, although new data sets (for example, from remote sensing) providing globally consistent information make a global assessment like the MA more rigorous, there are still many challenges that must be dealt with in using these data at global or local scales. Among these challenges are biases in the geographic and temporal coverage of the data and in the types of data collected. Data availability for industrial countries is greater than that for developing ones, and data for certain resources such as crop production are more readily available than data for fisheries, fuelwood, or biodiversity. The MA makes extensive use of both biophysical and socioeconomic indicators, which combine data into policy-relevant measures that provide the basis for assessment and decision-making.

Models can be used to illuminate interactions among systems and drivers, as well as to make up for data deficiencies—for instance, by providing estimates where observations are lacking. The MA makes use of environmental system models that can be used, for example, to measure the consequences of land cover change for river flow or the consequences of climate change for the distribution of species. It also uses human system models that can examine, for instance, the impact of changes in ecosystems on production, consumption, and investment decisions by households or that allow the economy-wide impacts of a change in production in a particular sector like agriculture to be evaluated. Finally, integrated models, combining both the environmental and human systems linkages, can increasingly be used at both global and sub-global scales.

The MA incorporates both formal scientific information and traditional or local knowledge. Traditional societies have nurtured and refined systems of knowledge of direct value to those societies but also of considerable value to assessments undertaken at regional and global scales. This information often is unknown to science and can be an expression of other relationships between society and nature in general and of sustainable ways of managing natural resources in particular. To be credible and useful to decision-makers, all sources of information, whether scientific, traditional, or practitioner knowledge, must be critically assessed and validated as part of the assessment process through procedures relevant to the form of knowledge.

Since policies for dealing with the deterioration of ecosystem services are concerned with the future consequences of current actions, the development of scenarios of medium- to long-term changes in ecosystems, services, and drivers can be particularly helpful for decision-makers. Scenarios are typically developed through the joint involvement of decision-makers and scientific experts, and they represent a promising mechanism for linking scientific information to decision-making processes. They do not attempt to predict the future but instead are designed to indicate what science can and cannot say about the future consequences of alternative plausible choices that might be taken in the coming years.

The MA uses scenarios to summarize and communicate the diverse trajectories that the world's ecosystems may take in future decades. Scenarios are plausible alternative futures, each an example of what might happen under particular assumptions. They can be used as a systematic method for thinking creatively about complex, uncertain futures. In this way, they help us understand the upcoming choices that need to be made and highlight developments in the present. The MA developed scenarios that connect possible changes in drivers (which may be unpredictable or uncontrollable) with human demands for ecosystem services. The scenarios link these demands, in turn, to the futures of the services themselves and the aspects of human welfare that depend on them. The scenario building exercise breaks new ground in several areas:

- development of scenarios for global futures linked explicitly to ecosystem services and the human consequences of ecosystem change,
- consideration of trade-offs among individual ecosystem services within the "bundle" of benefits that any particular ecosystem potentially provides to society,
- assessment of modeling capabilities for linking socioeconomic drivers and ecosystem services, and
- consideration of ambiguous futures as well as quantifiable uncertainties.

The credibility of assessments is closely linked to how they address what is not known in addition to what is known. The consistent treatment of uncertainty is therefore essential for the clarity and utility of assessment reports. As part of any assessment process, it is crucial to estimate the uncertainty of findings even if a detailed quantitative appraisal of uncertainty is unavailable.

1.6 Strategies and Interventions

The MA assesses the use and effectiveness of a wide range of options for responding to the need to sustainably use, conserve, and restore ecosystems and the services they provide. These options include incorporating the value of ecosystems in decisions, channeling diffuse ecosystem benefits to decision-makers with focused local interests, creating markets and property rights, educating and dispersing knowledge, and investing to improve ecosystems and the services they provide. As seen in Box 1.2 on the MA conceptual framework, different types of response options can affect the relationships of indirect to direct drivers, the influence of direct drivers on ecosystems, the human demand for ecosystem services, or the impact of changes in human well-being on indirect drivers. An effective strategy for managing ecosystems will involve a mix of interventions at all points in this conceptual framework.

Mechanisms for accomplishing these interventions include laws, regulations, and enforcement schemes; partnerships and collaborations; the sharing of information and knowledge; and public and private action. The choice of options to be considered will be greatly influenced by both the temporal and the physical scale influenced by decisions, the uncertainty of outcomes, cultural context, and the implications for equity and trade-offs. Institutions at different levels have different response options available to them, and special care is required to ensure policy coherence.

Decision-making processes are value-based and combine political and technical elements to varying degrees. Where technical input can play a role, a range of tools is available to help decision-makers choose among strategies and interventions, including cost-benefit analysis, game theory, and policy exercises. The selection of analytical tools should be determined by the context of the decision, key characteristics of the decision problem, and the criteria considered to be important by the decision-makers. Information from these analytical frameworks is always combined with the intuition, experience, and interests of the decision-maker in shaping the final decisions.

Risk assessment, including ecological risk assessment, is an established discipline and has a significant potential for informing the decision process. Finding thresholds and identifying the potential for irreversible change are important for the decision-making process. Similarly, environmental impact assessments designed to evaluate the impact of particular projects and strategic environmental assessments designed to evaluate the impact of policies both represent important mechanisms for incorporating the findings of an ecosystem assessment into decision-making processes.

Changes also may be required in decision-making processes themselves. Experience to date suggests that a number of mechanisms can improve the process of making decisions about ecosystem services. Broadly accepted norms for decision-making process include the following characteristics. Did the process:

- bring the best available information to bear?
- function transparently, use locally grounded knowledge, and involve all those with an interest in a decision?

- pay special attention to equity and to the most vulnerable populations?
- use decision analytical frameworks that take account of the strengths and limits of individual, group, and organizational information processing and action?
- consider whether an intervention or its outcome is irreversible and incorporate procedures to evaluate the outcomes of actions and learn from them?
- ensure that those making the decisions are accountable?
- strive for efficiency in choosing among interventions?
- take account of thresholds, irreversibility, and cumulative, cross-scale, and marginal effects and of local, regional, and global costs, risk, and benefits?

The policy or management changes made to address problems and opportunities related to ecosystems and their services, whether at local scales or national or international scales, need to be adaptive and flexible in order to benefit from past experience, to hedge against risk, and to consider uncertainty. The understanding of ecosystem dynamics will always be limited, socioeconomic systems will continue to change, and outside determinants can never be fully anticipated. Decision-makers should consider whether a course of action is reversible and should incorporate, whenever possible, procedures to evaluate the outcomes of actions and learn from them. Debate about exactly how to do this continues in discussions of adaptive management, social learning, safe minimum standards, and the precautionary principle. But the core message of all approaches is the same: acknowledge the limits of human understanding, give special consideration to irreversible changes, and evaluate the impacts of decisions as they unfold.

Chapter 2

Current State and Trends: Ecosystems and Their Services around the Year 2000

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CONTENTS

Human Well-being and Life on Earth

- Human well-being depends, among other things, on the continued supply of services obtained from ecosystems.
- Human actions during the last 50 years have altered ecosystems to an extent and degree unprecedented in human history. The consequences for human well-being have been mixed. Health and wealth have, on average, improved, but the benefits are unevenly distributed and further improvement may be limited by an insufficient supply of key ecosystem services.
- Biological diversity is a necessary condition for the delivery of all ecosystem services. In most cases, greater biodiversity is associated with a larger or more dependable supply of ecosystem services. Diversity of genes and populations is currently declining in most places in the world, along with the area of near-natural ecosystems.

Inescapable Link between Ecosystem Condition and Human Well-being

All people depend on the services supplied by ecosystems, either directly or indirectly. Services are delivered both by "near-natural" ecosystems, such as rangelands, oceans, and forests, and by highly managed ecosystems such as cultivated or urban landscapes.

Human well-being, by several measures and on average across and within many societies, has improved substantially over the past two centuries and continues to do so. The human population in general is becoming better nourished. People live longer, and incomes have risen. Political institutions have become more participatory. In part these gains in well-being have been made possible by exploiting certain ecosystem services (the provisioning services, such as timber, grazing, and crop production), sometimes to the detriment of the ecosystem and its underlying capacity to continue to provide these and other services. Some gains have been made possible by the unsustainable use of other resources. For example, the increases in food production have been partly enabled by drawing on the finite supply of fossil fuels, an ecosystem service laid down millions of years ago.

The gains in human well-being are not distributed evenly among individuals or social groups, nor among the countries they live in or the ecosystems of the world. The gap between the advantaged and the disadvantaged is increasing. For example, a child born in sub-Saharan Africa is 20 times more likely to die before age five than a child born in an industrial country, and this ratio is higher than it was a decade ago. People living in urban areas, near coasts, and in systems with high ecosystem productivity in general have above-average well-being. **People living in drylands and mountainous areas, both characterized by lower ecosystem productivity, tend to have below-average, and more variable, well-being.**

Populations are growing faster in ecosystems characterized by low well-being and low ecosystem productivity than in high well-being, high productivity areas. Figure C1, which uses GDP as a proxy for human well-being, illustrates this situation. Trends are similar for other measures of human well-being, such as infant mortality rate. [C5, 6, 16, 22]

Many human and ecological systems are under multiple severe and mutually reinforcing stresses. The causes include the direct and indirect impacts of extraction of services themselves, as well as the unintended side effects of other human activities. Certain linked ecological-human systems, by virtue of their structure or location, are more sensitive to stress than others. Examples include freshwater, coastal, mountain, island, and dryland systems.

Some groups of people are disproportionately likely to experience loss of well-being associated with declining levels of ecosystem services. The billion people poorest people in the world mostly live in rural areas where they are directly dependent on croplands, rangelands, rivers, seas, and forests for their livelihoods. For them especially, mismanagement of ecosystems threatens survival. Among better-off and urban populations, ecosystem changes affect well-being in less direct ways, but they remain important. They are partly buffered by technology and the ability to substitute some resources with others, but they also remain ultimately dependent on ecosystems for the basic necessities of life. Impacts are experienced differentially as a function of adaptive capacity, which can be manifested at the individual, household, community, national, or regional level. The groups ultimately responsible for the loss or decline of ecosystem services are often not the ones that bear the immediate impacts of their decline.

A large and growing number of people are at high risk of adverse ecosystem changes. The world is experiencing a worsening trend of human suffering and economic losses from natural disasters. Over the past four decades, for example, the number of weather-related disasters affecting at least a million people has increased fourfold, while economic losses have increased tenfold. The greatest loss of life has been concentrated in developing countries. Ecosystem transformation has played a significant, but not exclusive, role in increasing the vulnerability of people to such disasters. Examples are the increased susceptibility of coastal populations to tropical storms when mangrove forests are cleared and the increase in downstream flooding that followed land use changes in the upper Yangtze River. [C16]

Special Role of Biodiversity in Supplying Ecosystem Services

In some cases, biodiversity can be treated as an ecosystem service in its own right, such as when it is the basis of nature-based tourism or the regulation of diseases. In other respects, it is a necessary condition underpinning the long-term provision of other services, such as food and clean fresh water. **Variation among genes, populations, and species and the variety of structure, function, and composition of ecosystems are necessary to maintain an acceptable and resilient level of ecosystem services in the long term.** [C1]

For ecosystem functions such as productivity and nutrient cycling, the level, constancy of the service

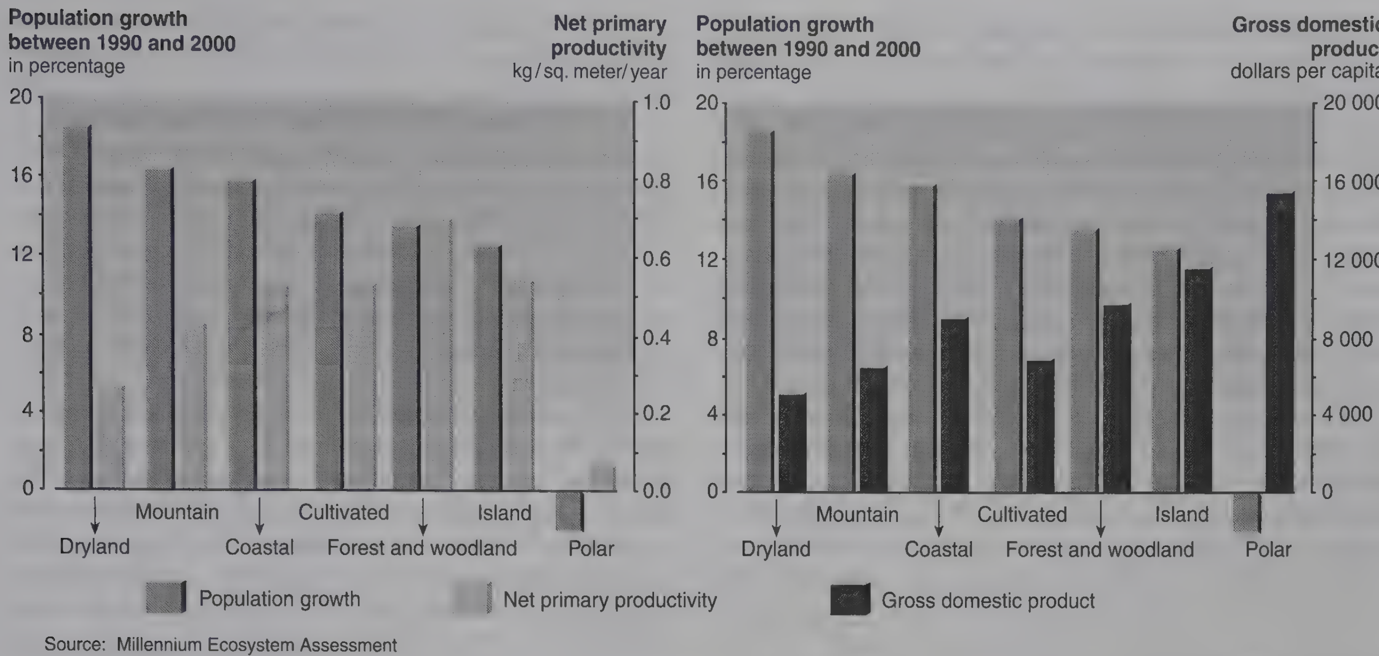

Figure C1. Population Growth Rates in 1990–2000, Per Capita GDP, and Ecosystem Productivity in 2000 in MA Ecological Systems

over time, and resilience to shocks all decline over the long term if biodiversity declines (*established but incomplete*). In general, there is no sudden biodiversity threshold below which ecosystem services fail. Quantifying the relationship between biodiversity and levels of ecosystem function has only been achieved in a few experimental situations and remains an area of active research. The amount and type of biodiversity required varies from service to service. **Regulatory services generally need higher levels of biodiversity than provisioning services do.** [C11]

Changes in species composition can alter ecosystem processes even if the number of species present remains unchanged or increases. Thus, conserving the composition of communities rather than simply maximizing species numbers is more likely to maintain higher levels of ecosystem services. Reduction of the number of species, especially if the species lost are locally rare, may have a hardly detectable effect on ecosystem services in the short term. However, there is evidence from terrestrial and aquatic systems that a rich regional species pool is needed to maintain ecosystem stability in the face of a changing environment in the long term. [C11]

The integrity of the interactions between species is critical for the long-term preservation of human food production on land and in the sea. For example, pollination is an essential link in the production of food and fiber. Plant-eating insects and pathogens control the populations of many potentially harmful organisms. The services provided by coral reefs, such as habitat and nurseries for fish, sediment stabilization, nutrient cycling, and carbon fixing in nutrient-poor environments, can only be maintained if the interaction between corals and their obligate symbiotic algae is preserved. [C11]

The preservation of genetic variation among crop species and their wild relatives and spatial heterogeneity in agricultural landscapes are considered necessary for the long-term viability of agriculture. Genetic variability is the raw material on which plant breeding for increased production and greater resilience depends. In general practice, agriculture undermines biodiversity and the regulating and supporting ecosystem services it provides in two ways: through transforming ecosystems by converting them to cultivated lands (extensification) and through the unintended negative impacts of increased levels of agricultural inputs, such as fertilizers, biocides, irrigation, and mechanical tillage (intensification). Agroforestry systems, crop rotations, intercropping, and conservation tillage are some of the agricultural techniques that maintain yields and protect crops and animals from pests without heavy investment in chemical inputs. [C11]

A large proportion of the world's terrestrial species are concentrated in a small fraction of the land area, mostly in the tropics, and especially in forests and on mountains. Marine species are similarly concentrated, with the limited area of coral reefs, for example, having exceptionally high biodiversity. Most terrestrial species have small geographical ranges, and the ranges are often clustered, leading to diagnosable "hotspots" of both richness and endemism. These are frequently, but not exclusively, concentrated in isolated or topographically variable regions such as islands, peninsulas, and mountains. The African and American tropics have the highest recorded species numbers in both absolute terms and per unit of area. Endemism is also highest there and, as a consequence of its isolation, in Australasia. Locations of species richness hotspots broadly correspond with centers of evolutionary diversity. Available evidence suggests that across the major taxa, tropical humid forests are especially important for both overall diversity and their unique evolutionary history. [C4]

Among plants and vertebrates, the great majority of species are declining in distribution, abundance, or both, while a small number are expanding. Studies of African mammals, birds in cultivated landscapes, and commercially important fish all show the majority of species to be declining in range or number. Exceptions can be attributed to management interventions such as protection in reserves and elimination of threats such as overexploitation, or they are species that thrive in human-dominated landscapes. In some regions there may be an increase in local biodiversity as a result of species introductions, the long-term consequences of which are hard to foresee. [C4]

The observed rates of species extinction in modern times are 100 to 1,000 times higher than the average rates for comparable groups estimated from the fossil record (*medium certainty*). (See Figure C2.) The losses have occurred in all taxa, regions, and ecosystems but are particularly high in some—for instance, among primates, in the tropics, and in freshwater habitats. Of the approximately 1,000 recorded historical extinctions, most have been on islands. Currently and in the future, the most threatened species are found on the mainland, particularly in locations of habitat change and degradation. **The current rate of biodiversity loss, in aggregate and at a global scale, gives no indication of slowing, although there have been local successes in some groups of species. The momentum of the underlying drivers of biodiversity loss, and the consequences of this loss, will extend many millennia into the future.** [C4]

Less than a tenth of known plant and vertebrate species have been assessed in terms of their vulnerability to extinction ("conservation status"). Birds have the lowest proportion (12%) threatened with global extinction (defined as a high certainty of loss from throughout its range) in the near-to-medium term (*high certainty*). Among mammal species, 23% are threatened with extinction (*high certainty*). Of the amphibia for which sufficient information is available to make an assessment, 32% are threatened (*medium certainty*). For cycads (an ancient group of plants), 52% of the species are threatened, as are 25% of conifer species (*high certainty*). [C4]

The taxonomic groups with the highest proportion of threatened species tend to be those that rely on freshwater habitats. Extinction rates, based on the frequency of threatened species, are broadly similar across terrestrial biomes (broad ecosystem types). Most terrestrial extinctions during the coming century are predicted to occur in tropical forests, because of their high species richness. [C4]

Factors Causing Changes in Ecosystems

Increasing Demand for Ecosystem Services

Increasing consumption per person, multiplied by a growing human population, are the root causes of the increasing demand for ecosystem services. The global human population continues to rise, but at a progressively slower rate. The population increased from 3 billion to 6

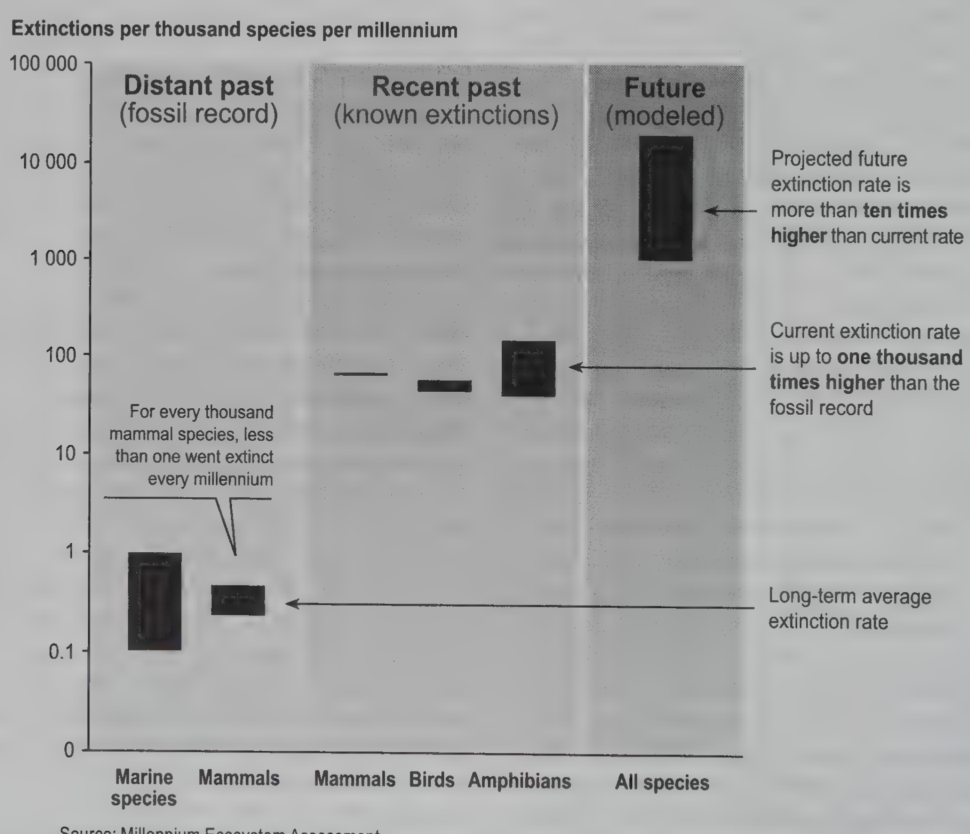

Figure C2. Species Extinction Rates Determined from the Fossil Record, from Observation, and from Estimation of Projected Rates

billion between 1960 and 2000 and is likely to peak at 8.2–9.7 billion around the middle of the twenty-first century. Migration to cities and population growth within cities continue to be major demographic trends. The world's urban population increased from about 200 million to 2.9 billion over the past century, and the number of cities with populations in excess of 1 million increased from 17 to 388. (See Figure C3.) [C3]

Overall demand for food, fiber, and water continue to rise. Improvements in human well-being, enabled by economic growth, almost invariably lead to an increase in the per capita demand for provisioning ecosystem services such as food, fiber, and water and in the consumption of energy and minerals and the production of waste. **In general, the increase in demand for provisioning services is satisfied at the expense of supporting, regulating, and cultural ecosystem services.** Efficiency gains permitted by new technology reduce per capita consumption levels below what they would have been without technological and behavioral adaptation, but they have tended not to keep pace with growth in demand for provisioning services. [C3]

Increasing Pollution and Waste

Ecosystem problems associated with contaminants and wastes are in general growing. Some wastes are produced in nearly direct proportion to population size (such as sewage). Others, such as domestic trash and home-use chemicals, reflect the affluence of society. Where there is significant economic development, waste loadings tend to increase faster than population growth. In some cases the per capita waste production subsequently decreases, but seldom to the pre-growth level. The generation of industrial wastes does not necessarily increase with population or development state, and it may often be reduced by adopting alternate manufacturing processes. The neglect of waste management leads to impairment of human health and well-being, economic losses, aesthetic value losses, and damages to biodiversity and ecosystem function. [C3, 15]

The oversupply of nutrients (eutrophication) is an increasingly widespread cause of undesirable ecosystem change, particularly in rivers, lakes, and coastal systems. Nutrient additions on the land, including synthetic fertilizers, animal manures, the enhancement of N-fixation by planted legumes, and the deposition of airborne pollutants, have resulted in approximately a doubling of the natural inputs for reactive nitrogen in terrestrial ecosystems and an almost fivefold increase in phosphorus accumulation. The reduction of biodiversity at the species and landscape levels has permitted nutrients to leak from the soil into rivers, the oceans, and the atmosphere. Emissions to the atmosphere are a significant driver of regional air pollution and the buildup of the greenhouse gas nitrous oxide (and, to a small extent, methane). [C3, 12, 19, 20]

Global Trade

The increasing volume of goods and services that are traded internationally, the distance that they are moved, the mobility of people, and the connectivity of local and global economies have all increased the spatial separation between cause and effect in ecosystem change. **Without appropriate regulation, global trade can be a key driver of overharvesting of resources such as high-value timber and marine resources.** Trade pressures and opportunities underlie patterns of land use change in many parts of the world. The movement of people and goods is an important vector in the spread of diseases and non-native invasive organisms. [C3]

Changing Climate

The effects of climate change on ecosystems are becoming apparent, especially in polar regions, where on average tem-

Figure C3. Human Population Density in 1995 and the Most Populated and Rapidly Changing Cities in 1990-2000

peratures are now warmer than at any time in the last 400 years and the Antarctic peninsular is one of the most rapidly warming regions on the planet; in mountains, where there has been widespread glacier retreat and loss of snowpack; and in coastal systems, where coral reefs in particular have been affected by sea temperature warming and increased carbon dioxide concentrations. Although many of the potential effects of climate change on ecosystem service provision to date have not been clearly distinguishable from short-term variations, **climate change over the next century is projected to affect, directly and indirectly, all aspects of ecosystem service provision.** [C3, 13, 19, 24, 25]

Overexploitation of Natural Resources

If a renewable natural resource is used at a faster rate than it is replenished, the result is a decline in the stock and eventually a decrease in the quantity of the resource that is available for human use. Overfishing, overgrazing, and overlogging are widespread examples of overexploitation. In the process of fishing, logging, mining, cultivation, and many other human activities, unintended collateral damage is done to ecosystems, affecting the supply of both the target resource and other services as well. When the net supply of ecosystem services is so damaged that it fails to recover spontaneously within a reasonable period after the level of the action causing the damage is reduced, the ecosystem is degraded. **Significant areas of forest, cultivated land, dryland rangelands, and coastal and marine systems are now degraded, and the degraded area continues to expand.** [C4]

Changing Land Use and Land Cover

Current rates of land cover change are greatest for tropical moist forests and for temperate, tropical, and flooded grasslands, with >14% of each of these lost between 1950 and 1990. Temperate broadleaf forests, Mediterranean forests, and grasslands had already lost more than 70% of their original extent by 1950. The rates of loss in these forest types have now slowed, and in some cases the forest area has expanded. Deforestation and forest degradation are currently focused in the tropics. Data on changes in boreal forests are especially limited. [C4, 21]

Habitat loss is the fastest-growing threat to species and populations on land and will continue to be the dominant factor for the next few decades. Fishing is the dominant factor reducing populations and fragmenting the habitats of marine species and is predicted to lead to local extinctions, especially among large, long-lived, slow-growing species and endemic species. [C4]

Habitat fragmentation (the reduction of natural cover into smaller and more disconnected patches) compounds the effects of habitat loss. The disruptive effects of fragmentation extend hundreds of meters inwards from the edges of the patches, making small patches highly vulnerable to loss of species and functions. [C11]

Invasion by Alien Species

In a wide range of terrestrial, marine, and freshwater ecosystems, accidental or voluntary introduction of non-native species by humans has altered local biological community interactions, triggering dramatic and often unexpected changes in ecosystem processes and causing large monetary and cultural losses. [C3, 4, 23]

Trends in Ecosystem Services

- **The supply of certain ecosystem services has increased at the expense of others. Significant gains in the provision of food and fiber have been achieved through habitat conversion, increased abstraction and degradation of inland waters, and reduced biodiversity.**
- **Fish cannot continue to be harvested from wild populations at the present rate. Deep-ocean and coastal fish stocks have changed substantially in most parts of the world and the harvests have begun to decline and will continue to do so.**
- **The supply of fresh water to people is already inadequate to meet human and ecosystem needs in large areas of the world, and the gap between supply and demand will continue to widen if current patterns of water use will continue.**
- **Declining trends in the capacity of ecosystems to render pollutants harmless, keep nutrient levels in balance, give protection from natural disasters, and control the outbreaks of pests, diseases, and invasive organisms are apparent in many places.**

The main trends in key ecosystem services over the last 50 years are summarized in Table C1. Individual ecosystem services are discussed below in further detail.

Provisioning Services

Food

Major inequalities exist in access to food despite the more than doubling of global production over the past 40 years. An estimated 852 million people were undernourished in 2000–02, up 37 million from 1997–99. [C8] There are important differences in the regional trends: the number of undernourished people in China is declining, while the number in Africa continues to increase. Of the global undernourished, 1% live in industrial countries, 4% live in countries in transition, and the remaining 95% are found in developing countries.

Figure C4 demonstrates that the economic value of food production is also not evenly distributed around the world, both because of the uneven distribution of natural factors such as climate and nutrient supply and because the prices obtained for food products vary according to demand and wealth. The impacts of activities associated with food production on other ecosystem services are unevenly distributed as well.

New cultivars of wheat, maize, and rice, coupled with increased inputs of fertilizers, irrigation, and an expansion of the cultivated area, were the main factors underlying the 250% increase in total cereal production since 1960. **The rate of increase of cereal production has slowed over the last decade,** for reasons that are uncertain but that include a long-term decline in the real price of cereals, a saturation in the per capita cereal consumption in many countries, a

Table C1. Trends in the Human Use of Ecosystem Services and Enhancement or Degradation of the Service around the Year 2000

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Provisioning Services					
Food	Crops	⬆	⬆	Food provision has grown faster than overall population growth. Primary source of growth from increase in production per unit area but also significant expansion in cropland. Still persistent areas of low productivity and more rapid area expansion, e.g., sub-Saharan Africa and parts of Latin America.	C8.2
	Livestock	⬆	⬆	Significant increase in area devoted to livestock in some regions, but major source of growth has been more intensive, confined production of chicken, pigs, and cattle.	C8.2
	Capture Fisheries	⬇	⬇	Marine fish harvest increased until the late 1980s and has been declining since then. Currently, one quarter of marine fish stocks are overexploited or significantly depleted. Freshwater capture fisheries have also declined. Human use of capture fisheries has declined because of the reduced supply, not because of reduced demand.	C18 C8.2.2 C19
	Aquaculture	⬆	⬆	Aquaculture has become a globally significant source of food in the last 50 years and, in 2000, contributed 27% of total fish production. Use of fish feed for carnivorous aquaculture species places an additional burden on capture fisheries.	C8 Table 8.4
	Wild plant and animal food products	NA	⬇	Provision of these food sources is generally declining as natural habitats worldwide are under increasing pressure and as wild populations are exploited for food, particularly by the poor, at unsustainable levels.	C8.3.1
Fiber	Timber	⬆	+/–	Global timber production has increased by 60% in the last four decades. Plantations provide an increasing volume of harvested roundwood, amounting to 35% of the global harvest in 2000. Roughly 40% of forest area has been lost during the industrial era, and forests continue to be lost in many regions (thus the service is degraded in those regions), although forest is now recovering in some temperate countries and thus this service has been enhanced (from this lower baseline) in these regions in recent decades.	C9.ES C21.1
	Cotton, hemp, silk	+/–	+/–	Cotton and silk production have doubled and tripled respectively in the last four decades. Production of other agricultural fibers has declined.	C9.ES
	Wood fuel	+/–	⬇	Global consumption of fuelwood appears to have peaked in the 1990s and is now believed to be slowly declining buts remains the dominant source of domestic fuel in some regions.	C9.ES
Genetic resources		⬆	⬇	Traditional crop breeding has relied on a relatively narrow range of germplasm for the major crop species, although molecular genetics and biotechnology provide new tools to quantify and expand genetic diversity in these crops. Use of genetic resources also is growing in connection with new industries base on biotechnology. Genetic resources have been lost through the loss of traditional cultivars of crop species (due in part to the adoption of modern farming practices and varieties) and through species extinctions.	C26.2.1

(continues)

Table C1. continued

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Biochemicals, natural medicines, and pharmaceuticals		↑	↓	Demand for biochemicals and new pharmaceuticals is growing, but new synthetic technologies compete with natural products to meet the demand. For many other natural products (cosmetics, personal care, bioremediation, biomonitoring, ecological restoration), use is growing. Species extinction and overharvesting of medicinal plants is diminishing the availability of these resources.	C10
Fresh water		↑	↓	Human modification to ecosystems (e.g., reservoir creation) has stabilized a substantial fraction of continental river flow, making more fresh water available to people but in dry regions reducing river flows through open water evaporation and support to irrigation that also loses substantial quantities of water. Watershed management and vegetation changes have also had an impact on seasonal river flows. From 5% to possible 25% of global freshwater use exceeds long-term accessible supplied and require supplied either through engineered water transfers of overdraft of groundwater supplies. Between 15% and 35% of irrigation withdrawals exceed supply rates. Fresh water flowing in rivers also provides a service in the form of energy that is exploited through hydropower. The construction of dams has not changed the amount of energy, but it has made the energy more available to people. The installed hydroelectric capacity doubled between 1960 and 2000. Pollution and biodiversity loss are defining features of modern inland water systems in many populated parts of the world.	C7
Regulating Services					
Air quality regulation		↑	↓	The ability of the atmosphere to cleanse itself of pollutants has declined slightly since preindustrial times but likely not by more than 10%. Then net contribution of ecosystems to this change is not known. Ecosystems are also a sink for tropospheric ozone, ammonia, NO_x, SO_2, particulates, and CH_4, but changes in these sinks were not assessed.	C13.ES
Climate regulation	Global	↑	↑	Terrestrial ecosystems were on average a net source of CO_2 during the nineteenth and early twentieth century and became a net sink sometime around the middle of the last century. The biophysical effect of historical land cover changes (1750 to present) is net cooling on a global scale due to increased albedo, partially offsetting the warming effect of associated carbon emissions from land cover change over much of that period.	C13.ES
	Regional and local	↑	↓	Changes in land cover have affected regional and local climates both positively and negatively, but there is a preponderance of negative impacts. For example, tropical deforestation and desertification have tended to reduce local rainfall.	C13.3 C11.3
Water regulation		↑	+/–	The effect of ecosystem change on the timing and magnitude of runoff, flooding, and aquifer recharge depends on the ecosystem involved and on the specific modifications made to the ecosystem.	C7.4.4

Erosion regulation		↑	↓	Land use and crop/soil management practices have exacerbated soil degradation and erosion, although appropriate soil conservation practices that reduce erosion, such as minimum tillage, are increasingly being adopted by farmers in North America and Latin America.	C26
Water purification and waste treatment		↑	↓	Globally, water quality is declining, although in most industrial countries pathogen and organic pollution of surface waters has decreased over the last 20 years. Nitrate concentration has grown rapidly in the last 30 years. The capacity of ecosystems to purify such wastes in limited, as evidenced by widespread reports of inland waterway pollution. Loss of wetlands has further decreased the ability of ecosystems to filter and decompose wastes.	C7.2.5 C19
Disease regulation		↑	+/−	Ecosystem modifications associated with development have often increased the local incidence of infectious diseases, although major changes in habitats can both increase or decrease the risk of particular infectious diseases.	C14
Pest regulation		↑	↓	In many agricultural areas, pest control provided by natural enemies has been replaced by the use of pesticides. Such pesticide use has itself degraded the capacity of agroecosystems to provide pest control. In other systems, pest control provided by natural enemies is being used and enhanced through integrated pest management. Crops containing pest-resistant genes can also reduce the need for application of toxic synthetic pesticides.	C11.3
Pollination		↑	↓[c]	There is *established but incomplete* evidence of a global decline in the abundance of pollinators. Pollinator declines have been reported in at least one region or country on every continent except for Antarctica, which has no pollinators. Declines in abundance of pollinators have rarely resulted in complete failure to produce seed or fruit, but more frequently resulted in fewer seeds or in fruit of reduced viability or quantity. Losses in populations of specialized pollinators have directly affected the reproductive ability of some rare plants.	C11 Box 11.2
Natural hazard regulation		↑	↓	People are increasingly occupying regions and localities that are exposed to extreme events, thereby exacerbating human vulnerability to natural hazards. This trend, along with the decline in the capacity of ecosystems to buffer from extreme events, has led to continuing high loss of life globally and rapidly rising economic losses from natural disasters.	C16 C19
Cultural Services					
Cultural diversity		**NA**	**NA**		
Spiritual and religious values		↑	↑	There has been a decline in the numbers of sacred groves and other such protected areas. The loss of particular ecosystem attributes (sacred species or sacred forests), combined with social and economic changes, can sometimes weaken the spiritual benefits people obtain from ecosystems. On the other hand, under some circumstances (e.g., where ecosystem attributes are causing significant threats to people), the loss of some attributes may enhance spiritual appreciation for what remains.	C17.2.3

(continues)

Table C1. continued

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Knowledge systems		NA	NA		
Educational values		NA	NA		
Inspiration		NA	NA		
Aesthetic values		⬆	⬇	The demand for aesthetically pleasing natural landscapes has increased in accordance with increased urbanization. There has been a decline in quantity and quality of areas to meet this demand. A reduction in the availability of and access to natural areas for urban residents may have important detrimental effects on public health and economies.	C17.2.5
Social relations		NA	NA		
Sense of place		NA	NA		
Cultural heritage values		NA	NA		
Recreation and ecotourism		⬆	+/–	The demand for recreational use of landscapes is increasing, and areas are increasingly being managed to cater for this use, to reflect changing cultural values and perceptions. However, many naturally occurring features of the landscape (e.g., coral reefs) have been degraded as resources for recreation.	C17.2.6 C19
Supporting Services					
Soil formation		†	†		
Photosynthesis		†	†		
Primary production		†	†	Several global MA systems, including drylands, forest, and cultivated systems, show a trend of NPP increase for the period 1981 to 2000. However, high seasonal and inter-annual variations associated with climate variability occur within this trend on the global scale	C22.2.1
Nutrient cycling		†	†	There have been large-scale changes in nutrient cycles in recent decades, mainly due to additional inputs from fertilizers, livestock waste, human wastes, and biomass burning. Inland water and coastal systems have been increasingly affected by eutrophication due to transfer of nutrients from terrestrial to aquatic systems as biological buffers that limit these transfers have been significantly impaired.	C12
Water cycling		†	†	Humans have made major changes to water cycles through structural changes to rivers, extraction of water from rivers, and, more recently, climate change.	C7

[a] For provisioning services, human use increases if the human consumption of the service increases (e.g., greater food consumption); for regulating and cultural services, human use increases if the number of people affected by the service increases. The time frame is in general the past 50 years, although if the trend has changed within that time frame, the indicator shows the most recent trend.

[b] For provisioning services, we define enhancement to mean increased production of the service through changes in area over which the service is provided (e.g., spread of agriculture) or increased production per unit area. We judge the production to be degraded if the current use exceeds sustainable levels. For regulating and supporting services, enhancement refers to a change in the service that leads to greater benefits for people (e.g., the service of disease regulation could be improved by eradication of a vector known to transmit a disease to people). Degradation of a regulating and supporting service means a reduction in the benefits obtained from the service, either through a change in the service (e.g., mangrove loss reducing the storm protection benefits of an ecosystem) or through human pressures on the service exceeding its limits (e.g., excessive pollution exceeding the capability of ecosystems to maintain water quality). For cultural services, degradation refers to a change in the ecosystem features that decreases the cultural (recreational, aesthetic, spiritual, etc.) benefits provided by the ecosystem. The time frame is in general the past 50 years, although if the trend has changed within that time frame the indicator shows the most recent trend.

[c] *Low to medium certainty.* All other trends are *medium to high certainty.*

Legend

⬆ = Increasing (for human use column) or enhanced (for enhanced or degraded column)

⬇ = Decreasing (for human use column) or degraded (for enhanced or degraded column)

+/− = Mixed (trend increases and decreases over past 50 years or some components/regions increase while others decrease)

NA = Not assessed within the MA. In some cases, the service was not addressed at all in the MA (such as ornamental resources), while in other cases the service was included but the information and data available did not allow an assessment of the pattern of human use of the service or the status of the service.

† = The categories of "human use" and "enhanced or degraded" do not apply for supporting services since, by definition, these services are not directly used by people. (Their costs or benefits would be double-counted if the indirect effects were included). Changes in supporting services influence the supply of provisioning, cultural, or regulating services that are then used by people and may be enhanced or degraded.

temporary decline in the use of cereals as livestock feed in the 1970s and 1980s, the declining quality of land in agricultural production, and diminishing returns to efforts aimed at improving yields of maize, wheat, and rice.

Adequate nutrition requires a diverse diet, containing sufficient micronutrients and protein as well as calories. The world's poorest people continue to rely on starchy staples, which leads to protein, vitamin, and mineral deficiencies. **Demand for high-value, protein-rich products such as livestock and fish has increased** with rising incomes in East and Southeast Asia (7% annual growth in livestock production over past 30 years). **The accelerating demand for animal protein is increasingly met by intensive ("industrial" or "landless") production systems,** especially for chicken and pigs. While these systems have contributed to large increases in production, they create serious waste problems and put increased pressure on cultivated systems and fisheries to provide feed inputs (and are thus not truly "landless").

The dietary changes that accompany increasing income can improve health; however, overconsumption, leading to obesity and heart disease, is also a growing health problem (65% of Americans and more than 17 million children in developing countries are overweight). Calorie intake is only 20% higher per capita in industrial countries than in developing countries on average, but protein intake is 50% higher and fat intake is almost twice as high.

Harvest pressure has exceeded maximum sustainable levels of exploitation in one quarter of all wild fisheries and is likely to exceed this limit in most other wild fisheries in the near future. In every ocean in the world, one or more important targeted stocks have been classified as collapsed, overfished, or fished to their maximum sustainable levels, and at least one quarter of im-

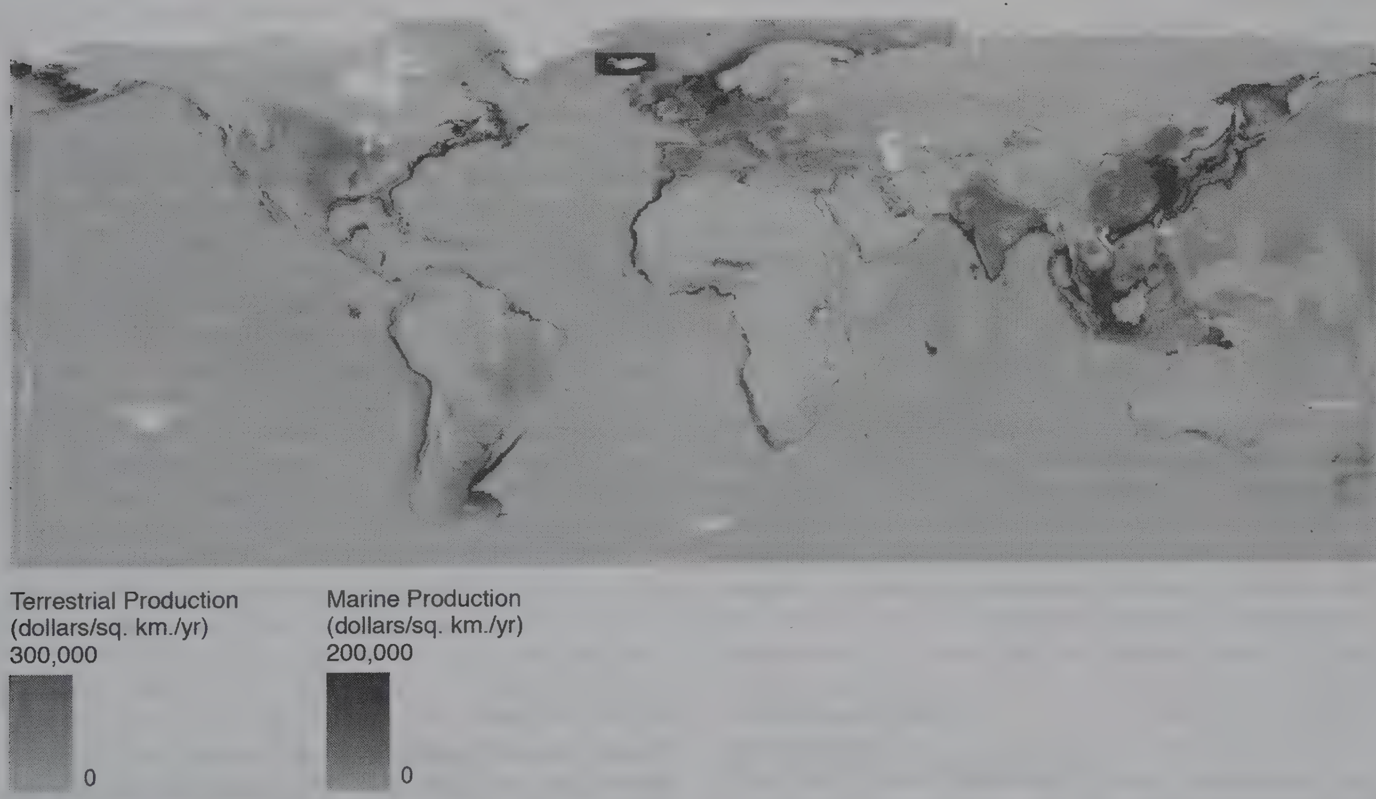

Figure C4. Spatial Distribution of Value of Food Production for Crops, Livestock, and Fisheries, 2000. This Figure was constructed by multiplying the harvest derived from all regions of the world by the average product price obtained in that region. (Data for Iceland were only available aggregated to the rectangular area shown.) A color version of this map appears in Appendix A (see Figure 8.2).

portant commercial fish stocks are overharvested (*high certainty*). Although fish consumption has doubled in developing countries in the last three decades, the per capita annual consumption has declined by 200 grams since 1985, to 9.2 kilograms per person (excluding China). Fish products are heavily traded, and approximately 50% of fish exports are from developing countries. Exports from developing countries and the Southern Hemisphere presently offset much of the demand shortfall in European, North American, and East Asian markets.

The growth in demand for fish protein is being met in part by aquaculture, which now accounts for 22% of total fish production and 40% of fish consumed as food. **Marine aquaculture has not to date relieved pressure on wild fisheries, because the food provided to captive fish is partly based on wild-harvested fish products.**

Government policies are significant drivers of food production and consumption patterns, both locally and globally. Investments in rural roads, irrigation, credit systems, and agricultural research and extension serve to stimulate food production. Improved access to input and export markets boosts productivity. Opportunities to gain access to international markets are conditioned by international trade and food safety regulations and by a variety of tariff and non-tariff barriers. Selective production and export subsidies stimulate overproduction of many food crops. This translates into relatively cheap food exports that benefit international consumers at the expense of domestic taxpayers and that undermine the welfare of food producers in poorer countries.

Wild terrestrial foods are locally important in many developing countries, often bridging the hunger gap created by stresses such as droughts and floods and social unrest. Wild foods are important sources of diversity in some diets, in that they are highly nutritious and are often not labor-intensive to collect or prepare. Although they have significant economic value, in most cases wild foods are excluded from economic analysis of natural resource systems as well as official statistics, so the full extent of their importance is poorly quantified.

Wood for Timber and Pulp

The absolute harvest of timber is projected, with *medium certainty*, to increase in the future, albeit at a slower rate than over the past four decades. [C9] The high growth in timber harvests since 1960 (60% and 300% for sawlogs and pulpwood respectively) has slowed in recent years. Total forest biomass in temperate and boreal regions increased over this period but decreased in mid-latitude and tropical forests. Demand for hardwoods is a factor in tropical deforestation, but is typically not the main driver. Conversion to agricultural land, a trend often underlain by policy decisions, is overall the major cause. **A third of timber is harvested from plantations rather than naturally regenerating forests, and this fraction is projected to grow.** Plantations currently constitute 5% of the global forest area. In general, plantations provide a less diverse set of ecosystem services than natural forests do.

Most trade in forest products is within-country, with only about 25% of global timber production entering international trade. However, international trade in forest products has increased three times faster in value than in harvested volume. The global value of timber harvested in 2000 was around $400 billion, about one quarter of which entered in world trade, representing some 3% of total merchandise traded. Much of this trade is among industrial countries: the United States, Germany, Japan, the United Kingdom, and Italy were the destination of more than half of the imports in 2000, while Canada, the United States, Sweden, Finland, and Germany account for more than half of the exports.

The global forestry sector annually provides subsistence and wage employment of 60 million work years, with 80% in the developing world. There is a trend in increasing employment in sub-tropical and tropical regions and declining employment in temperate and boreal regions.

Biomass Energy

Wood and charcoal remain the primary source of energy for heating and cooking for 2.6 billion people. [C9] Global consumption appears to have peaked in the 1990s and is now believed to be slowly declining as a result of switching to alternate fuels and, to a lesser degree, more-efficient biomass energy technologies. Accurate data on fuelwood production and consumption are difficult to collect, since much is produced and consumed locally by households. The global aggregate value of fuelwood production per capita has declined in recent years, easing concerns about a widespread wood energy crisis, although local and regional shortages persist.

Serious human health damages are caused by indoor pollution associated with the use of traditional biomass fuels in homes of billions of the rural and urban poor that lack adequate smoke venting. In 2000, 1.6 million deaths and the equivalent of 39 million person-years of ill health (disability-adjusted life years) were attributed to the burning of traditional biomass fuels, with women and children most affected. Health hazards increase where wood shortages lead to poor families using dung or agricultural residues for heating and cooking. Where adequate fuels are not available, the consumption of cooked foods declines, with adverse effects on nutrition and health. Local fuelwood shortages contribute to deforestation and result in lengthy and arduous travel to collect wood in rural villages, largely by women.

While examples of full commercial exploitation of modern biomass-based energy technologies are still fairly modest, their production and use is likely to expand over the next decades.

Agricultural Fibers

Global cotton production has doubled and silk production has tripled since 1961, with major shifts in the production regions. [C9] The total land area devoted to cotton production has stayed virtually constant; area expansion in India and the United States was offset by large declines in Pakistan and the former Soviet Union. These

shifts have impacts on land available for food crops and on water resources, since much of the cotton crop is irrigated. Silk production shifted from Japan to China. Production of wool, flax, hemp, jute, and sisal has declined.

Fresh Water

Water scarcity has become globally significant over the last four decades and is an accelerating condition for roughly 1–2 billion people worldwide, leading to problems with food production, human health, and economic development. Rates of increase in a key water scarcity measure (water use relative to accessible supply) from 1960 to the present averaged nearly 20% per decade globally, with values of 15% to more than 30% per decade for individual continents. Although a slowing in the global rate of increase in use is projected between 2000 and 2010, to 10% per decade, the relative use ratio for some regions is likely to remain high, with the Middle East and North Africa at 14% per decade, Latin America at 16%, and sub-Saharan Africa at 20%. [C7]

Contemporary water withdrawal is approximately 10% of global continental runoff, although this amounts to between 40% and 50% of the continental runoff to which the majority of the global population has access during the year.

Population growth and economic development have driven per capita levels of water availability down from 11,300 to about 5,600 cubic meters per person per year between 1960 and 2000. Global per capita water availability is projected (based on a 10% per decade rate of growth of water use, which is slower than the past decades) to drop below 5,000 cubic meters per person per year by 2010 (*high certainty*).

Terrestrial ecosystems are the major global source of accessible, renewable fresh water. Forest and mountain ecosystems are associated with the largest amounts of fresh water—57% and 28% of the total runoff, respectively. These systems each provide renewable water supplies to at least 4 billion people, or two thirds of the global population. Cultivated and urban systems generate only 16% and 0.2%, respectively, of global runoff, but due to their close proximity to humans they serve from 4.5–5 billion people. Such proximity is associated with nutrient and industrial water pollution.

More than 800 million people currently live in locations so dry that there is no appreciable recharge of groundwater or year-round contribution by the landscape to runoff in rivers. They are able to survive there by drawing on "fossil" groundwater, by having access to piped water, or by living along rivers that have their source of water elsewhere. From 5% to possibly 25% of global freshwater use exceeds long-term accessible supplies and is now met either through engineered water transfers or overdraft of groundwater supplies (*medium certainty*). In North Africa and the Middle East, nonsustainable use (use in excess of the long-term accessible renewable supply) represents 43% of all water use, and the current rate of use is 40% above that of the sustainable supply (*medium certainty*).

Growing competition for water is sharpening policy attention on the need to allocate and use water more efficiently. **Irrigation accounts for 70% of global water withdrawals (over 90% in developing countries),** but chronic inefficiencies in irrigated systems result in less than half of that water being used by crops.

The burden of disease from inadequate water, sanitation, and hygiene totals 1.7 million deaths and the loss of up to 54 million healthy life years per year. Some 1.1 billion people lack access to improved water supply and more than 2.6 billion lack access to improved sanitation. It is *well established* that investments in clean drinking water and sanitation show a close correspondence with improvement in human health and economic productivity. Half of the urban population in Africa, Asia, and Latin America and the Caribbean suffer from one or more diseases associated with inadequate water and sanitation.

The management of fresh water through dams, levees, canals, and other infrastructure has had predominantly negative impacts on the biodiversity of inland waters and coastal ecosystems, including fragmentation and destruction of habitat, loss of species, and reduction of sediments destined for the coastal zone. The 45,000 existing large dams (more than 15 meters high) generate both positive and negative effects on human well-being. Positive effects include flow stabilization for irrigation, flood control, and hydroelectricity. Negative effects include health issues associated with stagnant water and the loss of services derived from land that has become inundated. A significant economic consequence of soil erosion is the reduction of the useful life of dams lower in the drainage basin due to siltation.

Genetic Resources

The exploration of biodiversity for new products and industries has yielded major benefits for humanity and has the potential for even larger future benefits. [C10] The diversity of living things, at the level of the gene, is the fundamental resource for such "bioprospecting." While species-rich environments such as the tropics are in the long term expected to supply the majority of pharmaceutical products derived from ecosystems, bioprospecting to date has yielded valuable products from a wide variety of environments, including temperate forests and grasslands, arid and semiarid lands, freshwater ecosystems, mountain and polar regions, and cold and warm oceans.

The continued improvements of agricultural yields through plant breeding and the adaptation of crops to new and changing environments, such as increased temperatures, droughts, and emerging pests and diseases, requires the conservation of genetic diversity in the wild relatives of domestic species and in productive agricultural landscapes themselves.

Regulating Services

The Regulation of Infectious Diseases

Ecosystem changes have played a significant role in the emergence or resurgence of several infectious diseases of humans. [C14] The most important drivers are logging, dam building, road building, expansion of agri-

culture (especially irrigated agriculture), urban sprawl, and pollution of coastal zones. There is evidence that ecosystems that maintain a higher diversity of species reduce the risks of infectious diseases in humans living within them; the pattern of Lyme disease in North America is one example. **Natural systems with preserved structure and characteristics are not receptive to the introduction of invasive human and animal pathogens brought by human migration and settlement.** This is indicated for cholera, kala-azar, and schistosomiasis (*medium certainty*).

Increased human contact with ecosystems containing foci of infections raises the risk of human infections. Examples occur where urban systems are in close contact with forest systems (associated with malaria and yellow fever) and where cultivated lands are opened in forest systems (hemorrhagic fevers or hantavirus). Major changes in habitats can both increase or decrease the risk of a particular infectious disease, depending on the type of land use, the characteristics of the cycle of disease, and the characteristics of the human populations. Although disease emergence and reemergence due to ecosystem alteration can occur anywhere, people in the tropics are more likely to be affected in the future due to their greater exposure to reservoirs of potential disease and their greater vulnerability due to poverty and poorer health infrastructure.

Regulation of Climate, Atmospheric Composition, and Air Quality

Ecosystems are both strongly affected by and exert a strong influence on climate and air quality. [C13] **Ecosystem management has significantly modified current greenhouse gas concentrations.** Changes in land use and land cover, especially deforestation and agricultural practices such as paddy rice cultivation and fertilizer use, but also rangeland degradation and dryland agriculture, made a contribution of 15–25% to the radiative forcing of global climate change from 1750 to present.

Ecosystems are currently a net sink for CO_2 and tropospheric ozone, while they remain a net source of methane and nitrous oxide. About 20% of CO_2 emissions in the 1990s originated from changes in land use and land management, primarily deforestation.

Terrestrial ecosystems were on average a net source of CO_2 during the nineteenth and early twentieth centuries; they became a net sink sometime around the middle of the last century (*high certainty*) and were a sink for about a third of total emissions in the 1990s (energy plus land use). The sink may be explained partially by afforestation, reforestation, and forest management in North America, Europe, China, and other regions and partially by the fertilizing effects of nitrogen deposition and increasing atmospheric CO_2. The net impact of ocean biology changes on global CO_2 fluxes is unknown.

The potential of terrestrial ecosystem management to alter future greenhouse gas concentrations is significant through, for instance, afforestation, reduced deforestation, and conservation agriculture. However, the potential reductions in greenhouse gases remain much smaller than the projected fossil fuel emissions over the next century (*high certainty*). The management of ecosystems for climate mitigation can yield other benefits as well, such as biodiversity conservation.

Ecosystems also modify climate through alteration of the physical properties of Earth's surface. For instance, deforestation in snowy regions leads to regional cooling of land surface during the snow season due to increase in surface albedo and to warming during summer due to reduction in transpiration (water recycled by plants to atmosphere). Positive feedbacks involving sea surface temperature and sea ice propagate this cooling to the global scale. The net physically mediated effect of conversion of high-latitude forests to more open landscapes is to cool the atmosphere (*medium certainty*). Observations and models indicate, with *medium certainty*, that **large-scale tropical and sub-tropical deforestation and desertification decrease the precipitation in the affected regions.** The mechanism involves reduction in within-region moisture recycling and an increase in surface albedo. [C14]

Tropospheric ozone is both a greenhouse gas and an important pollutant. It is both produced and destroyed by chemical reactions in the atmosphere, and about a third of the additional tropospheric ozone produced as a result of human activities is destroyed by surface absorption in ecosystems. The capacity of the atmosphere to convert pollutants harmful to humans and other life forms into less harmful chemicals is largely controlled by the availability of hydroxyl radicals. The global concentration of these is believed to have declined by about 10% over the past centuries.

Detoxification of Wastes

Depending on the properties of the contaminant and its location in the environment, wastes can be rendered harmless by natural processes at relatively fast or extremely slow rates. The more slowly a contaminant is detoxified, the greater the possibility that harmful levels of the contaminant will occur. Some wastes, such as nutrients and organic matter, are normal components of natural ecosystem processes, but the anthropogenic loading rates are often so much higher than the natural throughput that they significantly modify the ecosystem and impair its ability to provide a range of services, such as recreation and appropriate-quality fresh water and air. **The costs of reversing damages to waste-degraded ecosystems are typically large, and the time scale for remediation is long. In some cases, rehabilitation is effectively impossible.** [C15]

Protection from Floods

The impact of extreme weather events is increasing in many regions around the world. [C7, 16, 19] For example, flood damage recorded in Europe in 2002 was higher than in any previous year. Increasing human vulnerability, rather than increasing physical magnitude or frequency of the events themselves, is overall the primary factor underlying the rising impact. People are increasingly occupying regions and locations that are exposed to flooding—settling on coasts and floodplains, for instance—thus exacerbating their vulnerability to extreme events. **Ecosys-**

tem changes have in some cases increased the severity of floods, however, for example as a result of deforestation in upland areas and the loss of mangroves. Local case studies have shown that appropriate management of ecosystems contributes to reduction of vulnerability to extreme events.

Cultural Services

Human societies have developed in close interaction with the natural environment, which has shaped their cultural identity, their value systems, and indeed their economic well-being. Human cultures, knowledge systems, religions, heritage values, social interactions, and the linked amenity services (such as aesthetic enjoyment, recreation, artistic and spiritual fulfillment, and intellectual development) have always been influenced and shaped by the nature of the ecosystem and ecosystem conditions in which culture is based. **Rapid loss of culturally valued ecosystems and landscapes has led to social disruptions and societal marginalization in many parts of the world.** [C17]

The world is losing languages and cultures. At present, the greatest losses are occurring in situations where languages are not officially recognized or populations are marginalized by rapid industrialization, globalization, low literacy, or considerable ecosystem degradation. Especially threatened are the languages of 350 million indigenous peoples, representing over 5,000 linguistic groups in 70 countries, which contain most of humankind's traditional knowledge. Much of the traditional knowledge that existed in Europe (such as knowledge on medicinal plants) has also gradually eroded due to rapid industrialization in the last century. [C17]

The complex relationships that exist between ecological and cultural systems can best be understood through both "formal knowledge" and "traditional knowledge." Traditional knowledge is a key element of sustainable development, particularly in relation to plant medicine and agriculture, and the understanding of tangible benefits derived from traditional ecological knowledge such as medicinal plants and local species of food is relatively well developed. However, understanding of the linkages between ecological processes and social processes and their intangible benefits (such as spiritual and religious values), as well as the influence on sustainable natural resource management at the landscape level, remains relatively weak. [C17]

Many cultural and amenity services are not only of direct and indirect importance to human well-being, they also represent a considerable economic resource. (For example, nature- and culture-based tourism employs approximately 60 million people and generates approximately 3% of global GDP.) Due to changing cultural values and perceptions, there is an increasing tendency to manage landscapes for high amenity values (such as recreational use) at the expense of traditional landscapes with high cultural and spiritual values. [C17]

Supporting Services

There are numerous examples of both overabundance and insufficiency of nutrient supply. Crop yields and nutritional value in parts of Africa, Latin America, and Asia are strongly limited by poor soils, which have become even more depleted by farming with low levels of nutrient replenishment. On the other hand, overfertilization is a major contributor to environmental pollution through excess nutrients in many areas of commercial farming in both industrial and developing countries.

The capacity of terrestrial ecosystems to absorb and retain the nutrients supplied to them either as fertilizers or from the deposition of airborne nitrogen and sulfur has been undermined by the radical simplification of ecosystems into large-scale, low-diversity agricultural landscapes. Excess nutrients leak into the groundwater, rivers, and lakes and are transported to the coast. Treated and untreated sewage released from urban areas adds to the load. The consequence of the excessive and imbalanced nutrient load in aquatic ecosystems is an explosion of growth of certain plants (particularly algae) and a loss of many other forms of life, a syndrome known as eutrophication. The decomposing residues of the plants (often compounded by organic pollutants) deplete the water of oxygen, creating anaerobic "dead zones" devoid of life forms that depend on oxygen. Such dead zones have been discovered in many lakes and estuaries and off the mouths of several large rivers, and they are expanding.

How Are Key Ecological Systems Doing?

The systems where multiple problems are occurring at the same time, seriously affecting the well-being of hundreds of millions of people, are:

- **wetlands, including rivers, lakes, and salt and saltwater marshes, where water abstraction, habitat loss and fragmentation, and pollution by nutrients, sediments, salts, and toxins have significantly impaired ecosystem function and biodiversity in most major drainage basins;**
- **the arid parts of the world, where a large, growing, and poor population often coincides with water scarcity, cultivation on marginal lands, overgrazing, and overharvesting of trees;**
- **particular coastal systems, notably coral reefs, estuaries, mangroves, and urbanized coasts, where habitat loss and fragmentation, overharvesting, pollution, and climate change are the key issues; and**
- **tropical forests, where unsustainable harvesting and clearing for agriculture threatens biodiversity and the global climate.**

The majority of ecosystems have been greatly modified by humans. Within 9 of the 14 broad terrestrial ecosystem types (biomes), one fifth to one half of the area has been transformed to croplands, mostly over the past two centuries. Tropical dry forests are the most affected by cultivation, with almost half of the biome's native habitats replaced with cultivated lands. Temperate grasslands, temperate broadleaf forests, and Mediterranean forests have each experienced more than 35% conversion. Only the biomes unsuited to crop plants (deserts, boreal forests, and tundra) are relatively intact. (See Table C2.) [C4]

Table C2. Comparative Table of Systems as Reported by the Millennium Ecosystem Assessment. Note that these are linked human and ecological systems and often are spatially overlapping. They can therefore be compared but they should not be added up. Figure C1 presents data on human well-being by system type graphically.

System and Subsystem	Area[a] (million sq. km.)	Share of Terrestrial Surface of Earth (percent)	Population Density (people per square km.) Urban	Rural	Population Growth rate (percent 1990–2000)	GDP per Capita (dollars)	Infant Mortality Rate[b] (deaths pers 1,000 live births)	Mean NPP (kg. carbon per sq. meter per year)	Share of Systems Covered by PAs[c] (percent)	Share of Area Transformed[d] (percent)
Marine	349.3	68.6[e]	–	–	–	–	–	0.15	0.3	-
Coastal	**17.2**	**4.1**	**1,105**	**70**	**15.9**	**8,960**	**41.5**	**–**	**7**	**–**
Terrestrial	6.0	4.1	1,105	70	15.9	8,960	41.5	0.52	4	11
Marine	11.2	2.2[e]	–	–	–	–	–	0.14	9	–
Inland water[f]	10.3	7.0	817	26	17	7,300	57.6	0.36	12	11
Forest/woodlands	**41.9**	**28.4**	**472**	**18**	**13.5**	**9,580**	**57.7**	**0.68**	**10**	**42**
Tropical/sub-tropical	23.3	15.8	565	14	17	6,854	58.3	0.95	11	34
Temperate	6.2	4.2	320	7	4.4	17,109	12.5	0.45	16	67
Boreal	12.4	8.4	114	0.1	−3.7	13,142	16.5	0.29	4	25
Dryland	**59.9**	**40.6**	**750**	**20**	**18.5**	**4,930**	**66.6**	**0.26**	**7**	**18**
Hyperarid	9.6	6.5	1,061	1	26.2	5,930	41.3	0.01	11	1
Arid	15.3	10.4	568	3	28.1	4,680	74.2	0.12	6	5
Semiarid	22.3	15.3	643	10	20.6	5,580	72.4	0.34	6	25
Dry subhumid	12.7	8.6	711	25	13.6	4,270	60.7	0.49	7	35
Island	**7.1**	**4.8**	**1,020**	**37**	**12.3**	**11,570**	**30.4**	**0.54**	**17**	**17**
Island states	4.7	3.2	918	14	12.5	11,148	30.6	0.45	18	21
Mountain	**35.8**	**24.3**	**63**	**3**	**16.3**	**6,470**	**57.9**	**0.42**	**14**	**12**
300–1,000m	13.0	8.8	58	3	127	7,815	48.2	0.47	11	13
1,000–2,500m	11.3	7.7	69	3	20.0	5,080	67.0	0.45	14	13
2,500–4,500m	9.6	6.5	90	2	24.2	4,144	65.0	0.28	18	6
> 4,500m	1.8	1.2	104	0	25.3	3,663	39.4	0.06	22	0.3
Polar	**23.0**	**15.6**	**161[g]**	**0.06[g]**	**−6.5**	**15,401**	**12.8**	**0.06**	**42[g]**	**0.3[g]**
Cultivated	**35.3**	**23.9**	**786**	**70**	**14.1**	**6,810**	**54.3**	**0.52**	**6**	**47**
Pasture	0.1	0.1	419	10	28.8	15,790	32.8	0.64	4	11
Cropland	8.3	5.7	1,014	118	15.6	4,430	55.3	0.49	4	62
Mixed (crop and other)	26.9	18.2	575	22	11.8	11,060	46.5	0.6	6	43
Urban	**3.6**	**2.4**	**681**	**–**	**12.7**	**12,057**	**36.5**	**0.47**	**0**	**100**
GLOBAL	**510**	**–**	**681**	**13**	**16.7**	**7,309**	**57.4**	**–**	**4**	**38**

[a] Area estimates based on GLC2000 dataset for the year 2000 except for cultivated systems where area is based on GLCCD v2 dataset for the years 1992–93 (C26 Box 1).

[b] Deaths of children less than one year old per 1,000 live births.

[c] Includes only natural protected areas in IUCN categories I to VI.

[d] For all systems except forest/woodland, area transformed is calculated from land depicted as cultivated or urban areas by GLC2000 land cover dataset. The area transformed for forest/woodland systems is calculated as the percentage change in area between potential vegetation (forest biomes of the WWF ecoregions) and current forest/woodland areas in GLC2000. Note: 22% of the forest/woodland system falls outside forest biomes and is therefore not included in this analysis.

[e] Percent of total surface of Earth.

[f] Population density, growth rate, GDP per capita, and growth rate for the inland water system have been calculated with an area buffer of 10 kilometers.

[g] Excluding Antarctica.

Freshwater Systems: Wetlands, Rivers, and Lakes

It is *established but incomplete* that **inland water ecosystems are in worse condition overall than any other broad ecosystem type,** and it is *speculated* that about half of all freshwater wetlands have been lost since 1900 (excluding lakes, rivers, and reservoirs). The degradation and loss of inland water habitats and species is driven by water abstraction, infrastructure development (dams, dikes, levees, diversions, and so on), land conversion in the catchment, overharvesting and exploitation, introduction of exotic species, eutrophication and pollution, and global climate change. [C20]

Clearing or drainage for agricultural development is the principal cause of wetland loss worldwide. It is estimated that by 1985, 56–65% of available wetland had been drained for intensive agriculture in Europe and North America, 27% in Asia, 6% in South America, and 2% in

Africa. **The construction of dams and other structures along rivers has resulted in fragmentation of almost 40% of the large river systems in the world.** This is particularly the case in river systems with parts of their basins in arid and semiarid areas. [C20]

The water requirements of aquatic ecosystems are in competition with human water demands. Changes in flow regime, transport of sediments and chemical pollutants, modification of habitat, and disruption of the migration routes of aquatic biota are some of the major consequences of this competition. Through consumptive use and interbasin transfers, **several of the world's largest rivers no longer run all the way to the sea for all or part of the year** (such as the Nile, the Yellow, and the Colorado). [C7]

The declining condition of inland waters is putting the services derived from these ecosystems at risk. The increase in pollution to waterways, combined with the degradation of wetlands, has reduced the capacity of inland waters to filter and assimilate waste. Water quality degradation is most severe in areas where water is scarce—arid, semiarid, and dry subhumid regions. Toxic substances and chemicals novel to the ecosystem are reaching waterways in increasing amounts with highly uncertain long-term effects on ecosystems and humans. [C20]

Estimates are that between 1.5 billion and 3 billion people depend on groundwater supplies for drinking. Groundwater is the source of water for 40% of industrial use and 20% of irrigation globally. In arid countries this dependency is even greater; for example, Saudi Arabia supplies nearly 100% of its irrigation requirement through groundwater. Overuse and contamination of groundwater aquifers are known to be widespread and growing problems in many parts of the world, although many pollution and contamination problems that affect groundwater supplies have been more difficult to detect and have only recently been discovered. [C7]

Inland waters have high aesthetic, artistic, educational, cultural, and spiritual values in virtually all cultures and are a focus of growing demand for recreation and tourism. [C20]

Dryland Systems: Deserts, Semiarid, and Dry Subhumid Rangelands

Drylands cover 41% of Earth's land surface and are inhabited by more than 2 billion people, about one third of the human population. **Semiarid drylands are the most vulnerable to loss of ecosystem services** (*medium certainty*), because they have a relatively high population in relation to the productive capacity of the system. [C22].

Desertification is the process of degradation in drylands, where degradation is defined as a persistent net loss of capacity to yield provisioning, regulating, and supporting ecosystem services. **Worldwide, about 10–20% of drylands are judged to be degraded** (*medium certainty*). The main causes of dryland degradation are grazing with domestic livestock and cutting of trees at rates exceeding the regrowth capacity of the ecosystem, inappropriate cultivation practices that lead to erosion and salinization of the soil, and climate change, which is affecting rates of evapotranspiration and precipitation.

Where the limits to sustainable cultivation and pastoralism have been reached, the promotion of alternative livelihoods such as production of crafts, tourism-related activities, and even aquaculture (such as aquatic organisms of high market value, cultured in often abundant drylands' low-quality water, within evaporation-proof containers) can take some pressure off dryland ecosystems and their services. [C22]

Wetlands in drylands, such as oases, rivers, and marshes, are disproportionately important in terms of the biodiversity that they support and the ecosystem services they provide. [C20, 22]

It is *well established* that desertification has adverse impacts in non-dryland areas, often many thousands of kilometers away. For example, dust storms resulting from reduced vegetative cover lead to air quality problems, both locally and far away. Drought and loss of land productivity are dominant factors that cause people to migrate from drylands to better-serviced areas. [C22]

Forests, Including Woodlands and Tree Plantations

The global area of naturally regenerating forest has declined throughout human history and has halved over the past three centuries. **Forests have effectively disappeared in 25 countries, and more 90% of the former forest cover has been lost in a further 29 countries.** [C21]

Following severe deforestation in past centuries, forest cover and biomass in North America, Europe, and North Asia are currently increasing due to the expansion of forest plantations and regeneration of natural forests. From 1990 to 2000, the global area of temperate forest increased by almost 3 million hectares per year, of which approximately 1.2 million hectares were was planted forest. The main location of deforestation is now in the tropics, where it has occurred at an average rate exceeding 12 million hectares per year over the past two decades. (See Figure C5.) **Taken as a whole, the world's forests are not managed in a sustainable way, and there is a total net decrease in global forest area, estimated at 9.4 million hectares per year.** In absolute terms, the rate and extent of woodland loss exceeds that of forests.

The decline in forest condition is caused, among other factors, by the low political power of human communities in forest areas in many countries; deforestation due to competitive land use and poor management; slow change of traditional, wood-oriented forest management paradigms; the lack of forest management on landscape-ecosystem basis; acceleration of natural and human-induced disturbance regimes during the last decade (possibly linked to climate change); and illegal harvest in many developing countries and countries with economies in transition, often linked to corruption. [C21]

In addition to the 3.3 billion cubic meters of wood delivered by forests annually, numerous non-wood forest products are important in the lives of hundreds of millions people. Several studies show that the combined economic value of "nonmarket" (social and ecological) services often exceeds the economic value of direct use of the timber, but

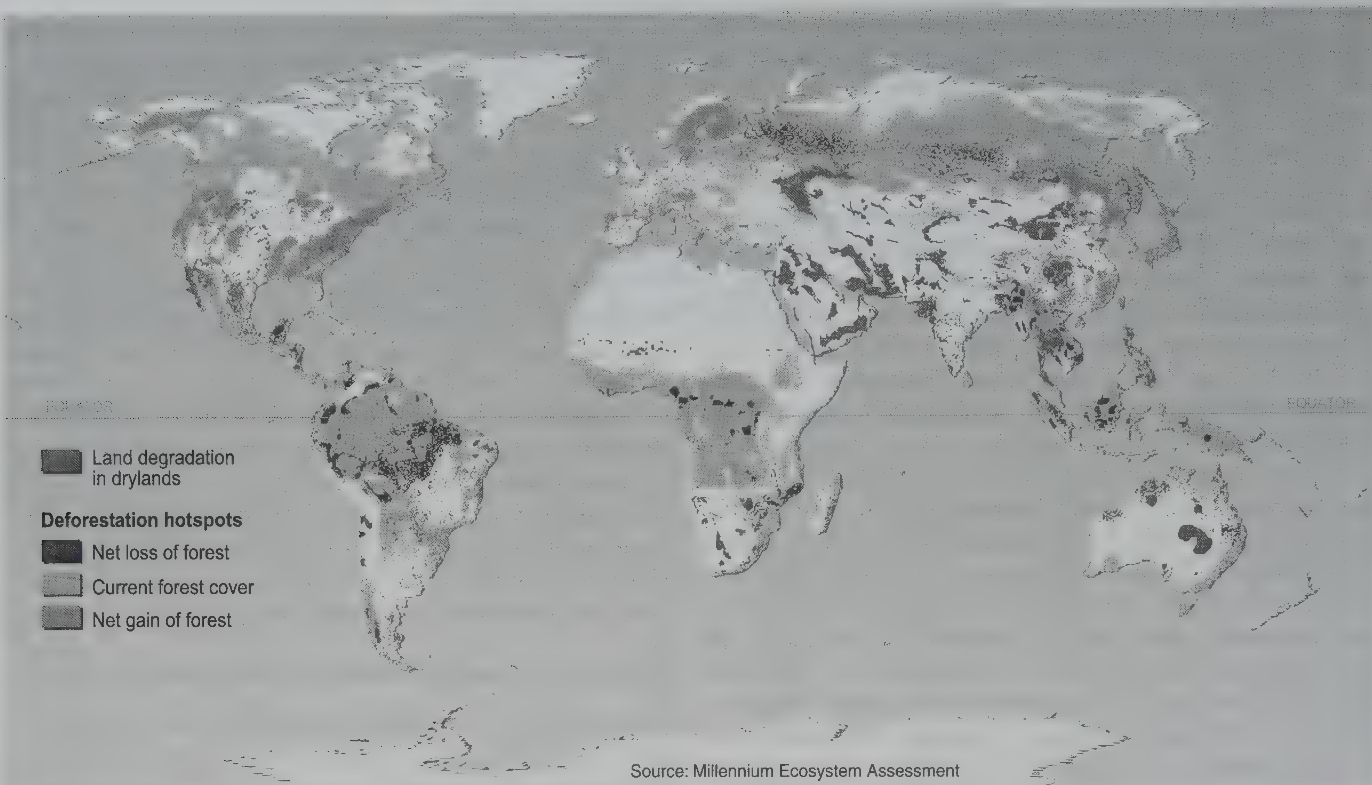

Figure C5. Locations Reported by Various Studies as Undergoing High Rates of Land Cover Change in the Past Few Decades. In the case of forest cover change, the studies refer to the period 1980–2000 and are based on national statistics, remote sensing, and to a limited degree expert opinion. In the case of land cover change resulting from degradation in drylands (desertification), the period is unspecified but inferred to be within the last half-century, and the major study was entirely based on expert opinion, with associated high levels of uncertainty. Change in cultivated area is not shown. Note that areas showing little current change are often locations that have already undergone major change.

the nonmarket values are usually not considered in the determination of forest use. Wooded landscapes are home to about 1.2 billion people, and **350 million of the world's people, mostly the poor, depend substantially for their subsistence and survival on local forests.** Forests and woodlands constitute the natural environment and almost sole source of livelihood for 60 million indigenous people and are important in the cultural, spiritual, and recreational life of communities worldwide. [C21]

Terrestrial ecosystems, and wooded lands in particular, are taking up about a fifth of the global anthropogenic emissions of carbon dioxide, and they will continue to play a significant role in limiting global climate change over the first decades of this century. Tree biomass constitutes about of 80% of terrestrial biomass, and **forests and woodlands contain about half of the world's terrestrial organic carbon stocks.** Forests and woodlands provide habitat for half or more of the world's known terrestrial plant and animal species, particularly in the tropics. [C21]

Marine and Coastal Systems

All the oceans of the world, no matter how remote, are now affected by human activities. Ecosystem degradation associated with fishing activities is the most widespread and dominant impact, with pollution as an additional factor on coastal shelves, and habitat loss a factor in populated coastal areas. [C18, 19]

Global fish landings peaked in the late 1980s and are now declining (*medium certainty*). There is little likelihood of this declining trend reversing under current practices. Fishing pressure is so strong in some marine systems that the biomass of targeted species, especially larger fishes as well as those caught incidentally, has been reduced by 10 times or more relative to levels prior to the onset of industrial fishing. **In addition to declining landings, the average trophic level of global landings is declining** (in other words, the high-value top-predator fish are being replaced in catches by smaller, less preferred species), and the mean size of caught fish is diminishing in many species, including yellowfin and bigeye tuna. [C18]

Industrial fleets are fishing further offshore and deeper to meet the global demand for fish. Until a few decades ago, depth and distance from coasts protected much of the deep-ocean fauna from the effect of fishing. Massive investments in the development of fishing capacity has led to fleets that now operate in all parts of the world's oceans, including polar areas, at great depths, and in low-productivity tropical zones. These trawl catches are extracted from easily depleted accumulations of long-lived species. The biomass of large pelagic fishes exploited by long liners, purse seiners, and drift netters have also plummeted. **Some fisheries that collapsed in recent decades show no signs of recovering**, such as Newfoundland cod stocks in

the northwest Atlantic and orange roughy in New Zealand. [C18]

Oil spills, depletions of marine mammals and seabirds, and ocean dumping also contribute to degradation in marine systems, especially at local and regional scales. Although major oils spills are infrequent, their impacts are severe when they do occur. Overfishing and pollution affect marine mammals and seabirds through declining food availability. An estimated 313,000 containers of low-intermediate radioactive waste dumped in the Atlantic and Pacific Oceans since 1970 pose a significant threat to deep-sea ecosystems should the containers leak. [C18]

Coastal ecosystems are among the most productive yet highly threatened systems in the world. Approximately 35% of mangroves for which data are available and 20% of coral reefs are estimated to have been destroyed, and a further 20% of corals degraded globally since 1960. Degradation is also a severe problem, both from pressures originating within the coastal zones and from the negative impacts of upstream land uses. Upstream freshwater diversion has meant a 30% decrease worldwide in water and sediment delivery to estuaries, which are key nursery areas and fishing grounds. [C19] Knowledge of cold-water corals is limited, and new large reefs are still being discovered. Cold-water coral reefs are estimated to have high species diversity, the biggest threat to which comes from fishery trawling activities.

The main indirect drivers of coastal ecosystem change are related to development activities on the land, particularly in areas adjacent to the coast. Approximately 17% of the world lives within the boundaries of the MA coastal system (up to an elevation of 50 meters above sea level and no further than 100 kilometers from a coast), and approximately 40% live in the full area within 100 kilometers of a coast. The absolute number is increasing through a combination of in-migration, high reproduction rates, and tourism. Physical demand on coastal space is increasing through urban sprawl, resort and port development, and aquaculture, the impacts of which extend beyond the direct footprints due to pollution, sedimentation, and changes in coastal dynamics. Destructive fishing practices, overharvesting, climate change, and associated sea level rise are also important threats to coastal habitats, including forests, wetlands, and coral reefs.

Nearly half of the coastal population has no access to improved sanitation and thus faces increasing risks of disease as well as decreasing ecosystem services as a result of pollution by human wastes. Harmful algal blooms and other pathogens affecting the health of both humans and marine organisms are on the rise. [C19] Nitrogen loading to the coastal zone has doubled worldwide and has driven coral reef community shifts. Alien species invasions have also altered coastal ecosystems and threaten both marine species and human well-being. [C18]

Island Systems

The ability of island systems to meet the rising demands of local populations for services has declined considerably, such that some islands are now unable to meet such demands without importing significant services from elsewhere. **Biodiversity loss and habitat destruction on islands can have more immediate and serious repercussions than on continental systems,** as a consequence of the relatively restricted genetic diversity, small population sizes and narrow distribution ranges of plants and animals on islands. Many studies show that specialization, coupled with isolation and endemism, make island ecosystems especially sensitive to disturbances. Island species have become extinct at rates that have exceeded those observed on continents, and the most important driver of wild population declines and species extinction on islands has been the introduction of invasive alien species. Although the idea that islands are more susceptible to biological invasion is poorly supported by current information, the impacts of invasive species once they are established are usually more rapid and more pronounced on islands. [C23]

In recent years tourism, especially nature-based tourism, has been the largest area of economic diversification for inhabited islands. However, unplanned and unregulated development has resulted in ecosystem degradation, including pollution, and loss of coral reefs, which is undermining the very resource on which the tourism sector is based. Alternative, more environmentally and culturally sensitive forms of tourism ("ecotourism") have developed in some areas. [C23]

Cultivated Systems: Croplands, Planted Pastures, and Agroforestry

Cultivated lands are ecosystems highly transformed and managed by humans for the purpose of providing food and fiber, often at the expense of other ecosystem services. **More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850, and one quarter of Earth's terrestrial surface is now occupied by cultivated systems.** (See Figure C6.) Within this area, one fifth is irrigated. [C26]

As the demand for food, feed, and fiber has increased, farmers have responded both by expanding the area under cultivation (extensification) and by raising yields per unit land and per unit time (intensification). **Over the past 40 years, in global aggregate, intensification has been the primary source of increased output,** and in many regions (including in the European Union, North America, Australia, and recently China) the extent of land under cultivation has stabilized or even contracted. However, countries with low productivity and high population pressure—conditions that apply in much of sub-Saharan Africa—continue to rely mainly on expansion of cultivated areas for increasing food productivity. In Asia (outside of China), almost no high-productivity land remains available for the expansion of agriculture. Area expansion usually brings more marginal land (steeper slopes, poorer soils, and harsher climates) into production, often with unwelcome social and environmental consequences. Urban expansion is a growing cause of displacement of cultivation, but the area involved remains small in global terms. [C26]

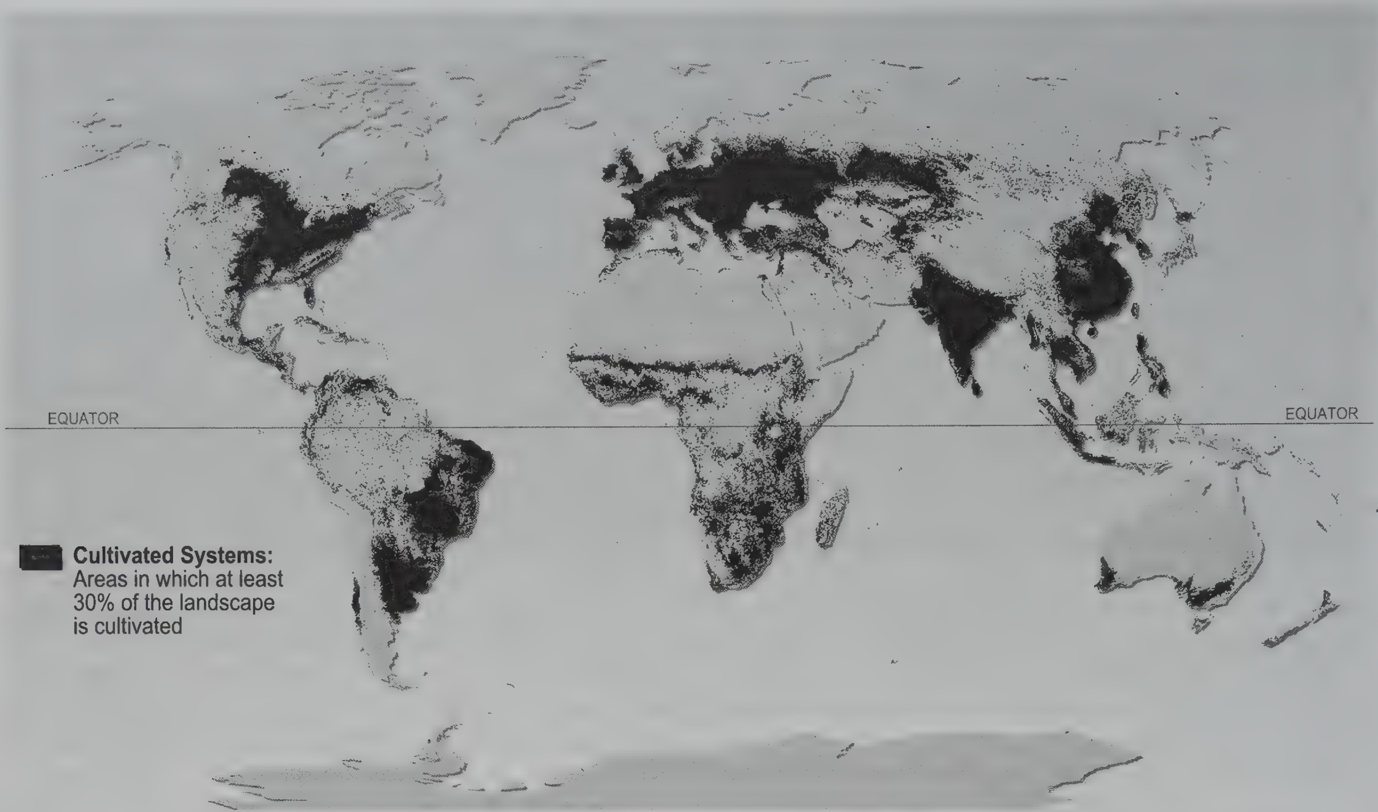

Figure C6. Extent of Cultivated Systems in 2000. Cultivated systems (defined in the MA to be areas in which at least 30% of the landscape comes under cultivation in any particular year) cover 24% of the terrestrial surface.

Increases in the yields of crop production systems due to increased use of inputs over the past 40 years have reduced the pressure to convert other ecosystems into cropland. Twenty million square kilometers of natural ecosystem have been protected from conversion to farmland since 1950 due to more intensive production. On the other hand, intensification has increased pressure on inland water ecosystems due to increased water withdrawals for irrigation and to nutrient and pesticide leakage from cultivated lands, with negative consequences for freshwater and coastal systems, such as eutrophication. Intensification also generally reduces biodiversity within agricultural landscapes and requires higher energy inputs in the form of mechanization and the production of chemical fertilizers. Especially in systems that are already highly intensified, the marginal value of further increased production must be weighed against the additional environmental impacts. [C26]

The intrinsic capacity of cultivated systems to support crop production is being undermined by soil erosion and salinization and by loss of agricultural biodiversity, but their effect on food production is masked by increasing use of fertilizer, water, and other agricultural inputs. (See Figure C7.) [C8, 22, 26]

National policies, international agreements, and market forces play a significant role in determining the fate of ecosystems services as a consequence of cultivation. They all influence farmer choices about the scale and type of cultivation as well as the level and mix of production inputs that, in turn, influence trade-offs among the mix and level of ecosystem services that cultivated systems can deliver. [C26]

Urban Systems

Urban areas currently cover less than 3% of the total land area of Earth, but they contain an increasing fraction of the world's population. Currently about half of the world's people live in urban areas. The urban requirements for ecosystem services are high, but it could be just as stressful if the same number of people, with similar consumption and production patterns, were dispersed over the rural landscape. In general, **the well-being of urban dwellers is higher than that of their rural neighbors,** as measured by wealth, health, and education indicators. Urban centers facilitate human access to and management of certain ecosystem services through, for example, the scale economies of piped water systems. [C27]

Nevertheless, urban developments pose significant challenges with respect to ecosystem services and human well-being. The problems include inadequate and inequitable access to ecosystem services within urban areas, degradation of ecosystems adjoining urban areas, and pressures on distant ecosystems resulting from production, consumption, and trade originating in urban areas. [C27]

In affluent countries, the negative impacts of urban settlements on ecosystem services and human well-being have been delayed and passed on to future generations or displaced onto locations away from the urban area. While urban developments in other parts

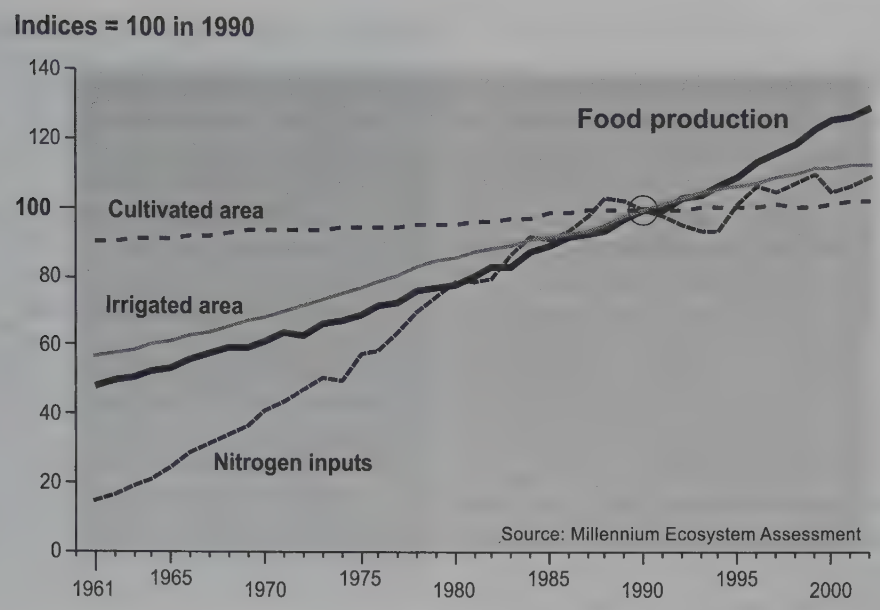

Figure C7. Trends in the Factors Related to Global Food Production since 1961. There have been significant trade-offs in cultivated systems between food production and water availability for other uses (due to irrigation), as well as water quality (due to increased nutrient loading). The role of improved crop varieties has also been extremely significant since 1961.

of the world have been quite different, this trend and its political implication remain significant. [C27]

Interrelated problems involving local water, sanitation, waste, and pests contribute a large share of the urban burden of disease, especially in low-income settlements. The consumption and production activities driving long-term, global ecosystem change are concentrated in urban centers, especially upper-income settlements. [C27]

Urbanization is not inherently bad for ecosystems: ecosystems in and around urban areas can provide a high level of biodiversity, food production, water services, comfort, amenities, cultural values, and so on if well managed. When the loss of ecosystem services due to urban activities is systematically addressed, these losses can be greatly reduced. With a few exceptions, however, there is little evidence of cities taking significant steps to reduce their global ecosystem burdens. A city may be sustained by ecosystem services derived from an area up to 100 times larger than the city itself. [C27]

Polar Systems

Direct, locally caused impacts of human activities on polar regions have been modest, and the most significant causes of change mainly originate outside the polar region. These global drivers must be addressed if loss of polar ecosystem services and human well-being is to be avoided, but in the immediate term, mitigation of impacts is the most feasible and urgent strategy. Polar regions have a high potential to continue providing key ecosystem services, particularly in wetlands, where biodiversity and use of subsistence resources are concentrated. [C25]

The climate has warmed more quickly in portions of the Arctic (particularly in the western North American Arctic and central Siberia) and Antarctic (especially the Antarctic peninsula) than in any other region on Earth. **As a consequence of regional warming, ecosystem services and human well-being in polar regions have been substantially affected** (*high certainty*). Warming-induced thaw of permafrost is widespread in Arctic wetlands, causing threshold changes in ecosystem services, including subsistence resources and climate feedbacks (energy and trace gas fluxes) and support for industrial and residential infrastructure.

Regional warming interacts with socioeconomic change to reduce the subsistence activities of indigenous and other rural people, the segment of society with greatest cultural and economic dependence on these resources. Warming has reduced access to marine mammals due to there being less sea ice and has made both the physical and the biotic environment less predictable. Industrial development has further reduced the capacity of ecosystems to support subsistence activities in some locations. The net effect is generally to increase the economic disparity between rural subsistence users and urban residents in polar regions. [C25]

Changes in polar biodiversity are affecting the resources on which Arctic people depend for their livelihoods. Important changes include increased shrub dominance in Arctic wetlands, which contributes to summer warming trends and alters forage available to caribou; changes in insect abundance that alter food availability to wetland birds and energy budgets of reindeer and caribou; increased abundance of snow geese that are degrading Arctic wetlands; and overgrazing by domestic reindeer in parts of Fennoscandia and Russia. There has also been a reduction of top predators in Antarctic food webs, altering marine food resources in the Southern Ocean. [C25]

Increases in persistent organic pollutants and radionuclides in subsistence foods have increased health risks in some regions of the Arctic, but diet changes associated with the decline in harvest of these foods are usually a greater health risk. [C25]

Mountain Systems

Mountain systems straddle all geographical zones and contain many different ecosystem types. Ninety percent of the 720 million people in the global mountain population live in developing and transition countries, with one third of them in China. **Almost all of the people living above 2,500 meters (about 70 million people) live in poverty and are especially vulnerable to food insecurity.**

Human well-being in lowland areas often depends on resources originating in mountain areas, such as timber, hydroelectricity, and water. Indeed, river basins from mountain systems supply nearly half of the human population with water, including in some regions far from the mountains themselves, and **loss of ecosystem functions in mountains increases environmental risks in both mountains and adjacent lowland areas.** However, there is rarely a systematic reinvestment of benefits derived from mountain systems in the conservation of upland resources. Mountains often represent political borders, narrow key transport corridors, or refuges for minorities and political opposition, and as such they are often focal areas of armed conflicts. [C24]

The compression of climatic zones along an elevation gradient in mountains results in large habitat diversity and species richness in mountains, which commonly exceeds that found in lowlands. Rates of endemism are also relatively high in mountains due to topographic isolation. Mountains occupy about one fifth of the terrestrial surface but host a quarter of terrestrial biodiversity, nearly half of the world's biodiversity "hotspots," and 32% of the global area designated for biodiversity protection. Mountains also have high ethnocultural diversity. Scenic landscapes and clean air make mountains target regions for recreation and tourism. [C24]

Mountain ecosystems are unusually exposed and sensitive to a variety of stresses, specifically climate-induced vegetative changes, volcanic and seismic events, flooding, loss of soil and vegetation caused by extractive industries, and inappropriate agricultural practices. On average, glaciers have lost 6–7 meters of depth (thickness) over the last 20 years, and this reduction in glacier volume is expected to have a strong impact on dry-season river flows in rivers fed largely by ice melt. **The specialized nature of mountain biota and low temperatures in mountain systems make recovery from disturbances typically very slow.** [C24]

Limits and Thresholds in Coupled Human-Ecological Systems

The current demand for many ecosystems services is unsustainable. If current trends in ecosystem services are projected, unchanged, to the middle of the twenty-first century, there is a high likelihood that widespread constraints on human well-being will result. This highlights the need for globally coordinated adaptive responses, a topic further explored in the MA *Scenarios* and *Policy Responses* volumes.

Limits, Trade-offs, and Knowledge

- **The growing demand for provisioning services, such as water, food, and fiber, has largely been met at the expense of supporting, regulating, and cultural ecosystem services.**
- **For some provisioning services, notably fresh water and wild-harvested fish, demand exceeds the available supply in large and expanding parts of the world.**
- **Some ongoing, large-scale human-induced ecosystem changes, such as those involving loss of biodiversity, climate change, excessive nutrient supply, and desertification, are effectively irreversible. Urgent mitigation action is needed to limit the degree of change and its negative impacts on human well-being.**
- **Enough is known to begin to make wiser decisions regarding protection and use of ecosystem services. Making this information available to decision-makers is the purpose of the Millennium Ecosystem Assessment.**

Some limits to the degree of acceptable ecosystem change represent the level of tolerance by society, reflecting the trade-offs that people are willing (or forced) to make between different aspects of well-being. They are "soft limits," since they are socially determined and thus move as social circumstances change. Many such limits are currently under international negotiation, indicating that some key ecosystem services are approaching levels of concern. Examples are the amounts of fresh water allocated to different countries in shared basins, regional air quality norms, and the acceptable level of global climate change.

Other limits are a property of the ecological system itself and can be considered "hard limits." Two types of hard limit are of concern. The first is nonlinearity, which represents a point beyond which the loss of ecosystem services accelerates, sometimes abruptly. An example is the nitrogen saturation of watersheds: once the absorptive capacity of the ecosystem is exceeded, there is a sudden increase in the amount of nitrogen leaking into the aquatic environment. The second type is a true system threshold that, if crossed, leads to a new regime from which return is difficult, expensive, or even impossible. An example is the minimum habitat area required to sustain a viable population of a given species. If the area falls below this, eventual extinction is inevitable. We have fallen below this limit for many thousands of species (*medium certainty*).

Abrupt and possibly irreversible change may not be widely apparent until it is too late to do much about it. The dynamics of both ecological and human systems have intrinsic inertia—the tendency to continue changing even when the forces causing the change are relieved. The complexity of coupled human–ecological systems, together with our state of partial knowledge, make it hard to predict precisely at what point such thresholds lie. The overexploitation of wild fisheries is an example of a threshold that has already been crossed in many regions. [C6, 13, 18, 25]

Thresholds of abrupt and effectively irreversible change are known to exist in the climate-ocean-land

system (*high certainty*), although their location is only known with *low to medium certainty*. For example, it is *well established* that a decrease in the vegetation cover in the Sahara several thousand years ago was linked to a decrease in rainfall, promoting further loss of cover, leading to the current dry Sahara. It is *speculated* that a similar mechanism may have been involved in the abrupt decrease in rainfall in the Sahel in the mid-1970s. There are potential thresholds associated with climate feedbacks on the global carbon cycle, but large uncertainties remain regarding the strength of the feedback processes involved (such as the extent of warming-induced increases in soil respiration, the risk of large-scale dieback of tropical forests, and the effects of CO_2, nitrogen, and dust fertilization on carbon uptake by terrestrial and marine ecosystems). [C12, 13, 22, 25]

Current human-induced greenhouse gas emissions to the atmosphere are greater than the capacity of global ecosystems to absorb them (*high certainty*). The oceans and terrestrial ecosystems are currently absorbing only about half of the carbon emissions resulting from fossil fuel combustion. As a result, the atmospheric concentration of CO_2 is rising, along with other greenhouse gases, leading to climate change. Although land use management can have a significant impact on CO_2 concentrations in the short term, future trends in atmospheric CO_2 are likely to depend more on fossil fuel emissions than on ecosystem change. [C13]

Nitrogen additions to the environment are approaching critical limits in many regions. The increasing extent of oxygen-poor "dead zones" in freshwater or coastal ecosystems that have received elevated inputs of nutrients—nitrogen and phosphorus, in particular—over long periods of time is a symptom of the degree to which the nutrient retention capacity of terrestrial and freshwater systems has been overloaded. [C12]

The capacity of Earth as a whole to render other waste products of human activities relatively harmless is unknown. It is *well established* that at high loading rates of wastes such as persistent organic pollutants, heavy metals, and radionuclides, the local ecosystem capacity can be overwhelmed, allowing waste accumulation to the detriment of human well-being and the loss of ecosystem biodiversity [C15]. A potential nonlinear response, currently the subject of intensive scientific research, is the atmospheric capacity to cleanse itself of air pollution (in particular, hydrocarbons and reactive nitrogen compounds). This capacity depends on chemical reactions involving the hydroxyl radical, the atmospheric concentration of which has declined by about 10% (*medium certainty*) since preindustrial times. [C13]

Understanding the Trade-offs Associated with Our Actions

The growth in human well-being over the last several decades has come in large part through increases in provisioning services, usually at the expense of other services. In particular:

- The substantial increase in the production of food and fiber has expanded the area of cultivated systems (including plantation forests) at the expense of semi-natural ecosystems such as forests, rangelands, and wetlands. It has largely been achieved as a result of large inputs of nutrients, water, energy, and pesticides, with deleterious consequences for other ecosystems and the global climate.
- Clearing and transformation of previously forested land for agricultural and timber production, especially in tropical and sub-tropical forests, has reduced the land's capacity to regulate flows of water, store carbon, and support biological diversity and the livelihoods of forest-dwelling people.
- Harvesting of fish and other resources from coastal and marine systems (which are simultaneously under pressure from elevated flows of nutrients, sediments, and pollutants from the land) has impaired these systems' capacity to continue to deliver food in the future.

This assessment has shown that although we have many of the conceptual and analytical tools to illustrate the existence of trade-offs, the detailed information required to quantify adequately even the main trade-offs in economic terms is generally either lacking or inaccessible. An example of a tool useful for trade-off analysis is the valuation of ecosystem services, but such valuations have only been done for a few services and in a few places. The MA has also shown that failure to fully comprehend the trade-offs associated with particular actions has, in many instances, resulted either in a net decrease in human well-being or in an increase that is substantially less than it could have been. Examples of this include the loss of non-wood products and watershed services from over-logged forests, the loss of timber and the declines in offshore fisheries and storm protection from conversion of mangroves to aquaculture, and the loss of wetland products from conversion to intensive agriculture. (See Figure C8.) The continued tendency to make decisions on a sectoral basis prevents trade-offs from being fully considered.

Several independently derived international goals and commitments are interconnected via the ecosystems they affect. Thoughtful and informed consideration of trade-offs and synergies would be best achieved by coordinated implementation. An example of the importance of ecosystem service trade-offs in the pursuit of human well-being is provided by the Millennium Development Goals. In meeting the goal of reducing hunger, for instance, progress toward the goal of environmental sustainability could be compromised, and vice versa. A narrowly sectoral approach often simply displaces problems to other sectors. Ecosystem approaches, as adopted by the Convention on Biological Diversity, the Ramsar Convention on Wetlands, the Food and Agriculture Organization, and others, show promise for improving the future condition of services and human well-being as a whole, specifically by balancing the objectives of economic development and ecosystem integrity. In managing ecosystems, a balance needs to be found between provisioning services on the one hand and supporting, regulating, cultural and amenity services on the other hand. [C7, 28]

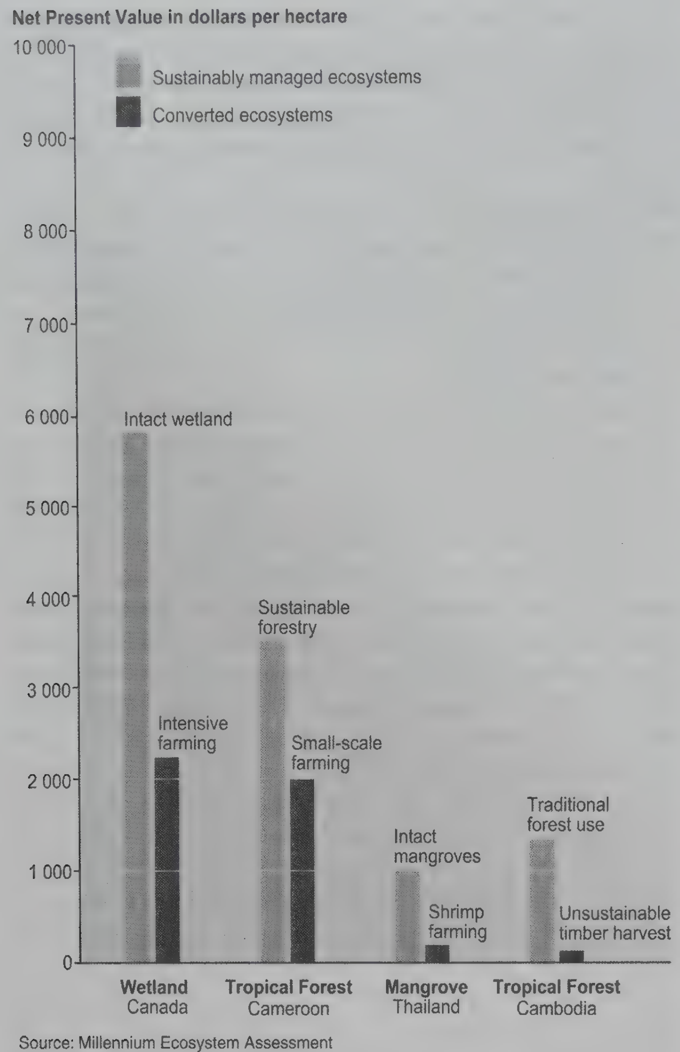

Figure C8. Economic Benefits under Alternate Management Practices. In each case, the net benefits from the more sustainably managed ecosystem are greater than those from the converted ecosystem even though the private (market) benefits would be greater from the converted ecosystem. (Where ranges of values are given in the original source, lower estimates are plotted here.)

Knowledge and Uncertainty

The experience of this assessment has been that it is hard to demonstrate, quantitatively and unequivocally, the widely accepted and intuitive link between ecosystem changes and changes in human well-being. There are several reasons for this. First, the impacts of ecosystem change on well-being are often subtle, which is not to say unimportant; impacts need not be blatant to be significant. Second, human well-being is affected by many factors in addition to the effects of ecosystem services. Health outcomes, for example, are the combined result of ecosystem condition, access to health care, economic status, and myriad other factors. Unequivocally linking ecosystem changes to changes in well-being, and vice versa, is especially difficult when the data are patchy in both cases, as they usually are. Analyses linking well-being and ecosystem condition are most easily carried out at a local scale, where the linkages can be most clearly identified, but information on ecosystems and human well-being is often only available in highly aggregated form, for instance at the national level. Spatially explicit data with sub-national resolution would greatly facilitate future assessments. [C2]

The availability and accuracy of data sources and methods for this assessment were greatest for provisioning services, such as crop yield and timber production. Direct data on regulating, supporting, and cultural services such as nutrient cycling, climate regulation, or aesthetic value are difficult to obtain, making it necessary to use proxies, modeled results, or extrapolations from case studies. Data on biodiversity have strong biases toward the species level, large organisms, temperate systems, and species used directly by people. [C2, 4, 28]

Knowledge for quantifying ecosystem responses to stress is equally uneven. Methods to estimate crop yield responses to fertilizer application, for example, are well developed, but methods to quantify relationships between ecosystem services and human well-being, such as the effects of altered levels of biodiversity on the incidence of diseases in humans, are at an earlier stage of development. Thousands of novel chemicals, including long-lived synthetic pharmaceuticals, are currently entering the biosphere, but there are few systematic studies to understand their impact on ecosystems and human well-being. [C2, 28]

Observation systems relating to ecosystem services are generally inadequate to support informed decision-making. Some previously more-extensive observation systems have declined in recent decades. For example, substantial deterioration of hydrographic networks is occurring throughout the world. The same is true for standard water quality monitoring and the recording of biological indicators. [C7]

Both "traditional" and "formal" knowledge systems have considerable value for achieving the conservation and sustainable use of ecosystems. The loss of traditional knowledge has significantly weakened the linkages between ecosystems and cultural diversity and cultural identity. This loss has also had a direct negative effect on biodiversity and the degradation of ecosystems, for instance by exceeding traditionally established norms for resource use. This knowledge is largely oral. As significant is the loss of languages, which are the vehicle by which cultures are communicated and reproduced. [C17]

A Call for Action

Despite the gaps in knowledge, **enough is known to indicate the need for urgent collective action, building on existing activities, to mitigate the further loss of ecosystem services.** It is *well established* that inadequate access to ecosystem services currently is an important factor in the low well-being of a large fraction of the global population and is likely to constrain improvements in well-being in the future.

Urgency is indicated because in situations where the probability of effectively irreversible, negative impacts is high, where the human and natural systems involved have

high inertia, and where knowledge of the consequences is incomplete, early action to reduce the rate of change is more rational than waiting until conditions become globally intolerable and potentially irreversible. **Collective action is required** because uncoordinated individual action is necessary but insufficient to mitigate the many issues that have large-scale underlying causes, mechanisms, or consequences. Coordinated action at all levels of social organization—from local to global—is called for if the many islands of local failure are not to coalesce into expanding regions of degradation and if problems with global reach are to be managed. Coordinated action is also required to enable islands of local success to be expanded and propagated in distant locations.

The history of human civilization has many examples of social upheaval associated with ecosystem service failure at the local or regional scale. There are many current examples where the demands on ecosystems are exceeding the limits of the system to supply ecosystem services. Global-scale examples are given in this report, and local and regional examples are found in the *Multiscale Assessments* volume. **Two things are different now compared with any other time in history: human impacts are now ubiquitous and of greater intensity than at any time in the past, and in most cases we can no longer plead ignorance of the consequences.** Whereas in the past, natural disasters, pollution, or resource depletion led to local hardships, realignment of power, and the regional migration of people to better-serviced areas, in the present era the impacts are global in reach. Displacement of the problem to other places and future generations, or starting afresh in a new place, are no longer viable options.

A turning point in the growth of the human population on Earth is likely by mid-century. As the *Scenarios* and *Policy Responses* volumes show, the opportunity and technical means exist to provide food, water, shelter, a less-hazardous environment, and a better life to the existing population, and even to the additional 3 billion people likely to inhabit Earth by the middle of the twenty-first century, but we are currently failing to achieve this. We are also undermining our capacity to do so in the future by failing to take actions that will reduce the risk of adverse changes in Earth's ecological systems that will be difficult and costly to reverse.

Reducing the pressure on critical systems and services will be neither easy nor cost-free, but it is certain that net human well-being is better served by maintaining ecosystems in a condition that is capable of providing adequate levels of essential services than by trying to restore such functions at some future time.

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A turning point in the growth of the human population on Earth is likely by mid century. As the [illegible] [illegible] [illegible] show the opportunity and [illegible] means exist to provide food, water, [illegible] environment, and a better life for the existing population and even to the additional 1 billion people likely [illegible] Earth by the middle of the twenty first century, but we are currently failing to achieve this.

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Chapter 3

Scenarios: Comparing Alternate Futures of Ecosystem Services and Human Well-being

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Envisioning the Future for Ecosystems and People

The capacity of Earth's ecosystems to provide life-support services is changing rapidly, at a time when human pressures on ecosystems are also increasing.

These changes in ecosystems have enormous implications for life on Earth. Yet they can seem bewildering because of their complexity, speed, surprises, and demands on human ingenuity.

Scenarios organize information about plausible causes of and responses to long-term change. The central idea is to categorize outcomes into a few plausible futures, making the complex more comprehensible. Contrasts among scenarios illuminate key linkages and probable outcomes of various approaches or decisions.

Ecosystems are always changing, but the rate and magnitude of change are not constant over time. Most of the time, change is gradual, incremental, and perhaps reversible. However, some changes in ecosystems and their services are large in magnitude and can be difficult, expensive, or impossible to reverse (*high certainty*). Examples of ecosystems subject to large, important changes are pelagic fisheries (economic collapse), freshwater lakes and reservoirs (toxic blooms, fish kills), pastoral lands (conversion to woodland with overgrazing and fire suppression), and dryland agriculture (desertification). The thresholds and triggering events for these large changes are often difficult to predict. [S3, 5]

Slow losses of resilience set the stage for large changes that occur after the ecosystem crosses a threshold or is subjected to a random event such as a climate fluctuation (*established but incomplete*). For example, incremental buildup of phosphorus in soils gradually increases the vulnerability of lakes and reservoirs to runoff events that trigger oxygen depletion, toxic algae blooms, and fish kills. Cumulative effects of overfishing and nutrient runoff make coral reefs susceptible to severe deterioration triggered by storms, invasive species, or disease. Slow decrease in grass cover crosses a threshold so that grasslands can no longer carry a fire, allowing woody vegetation to dominate and severely decreasing forage for livestock. [S3, 5] These long-lasting and costly changes from seemingly random events pose a daunting challenge for decision-makers concerned with ecosystems as well as for people whose livelihoods depend on ecosystems.

Recent trends in human use of ecosystem services reveal rapid changes and great uncertainty about future changes. (See MA *Current State and Trends* volume.) While many ecosystem services are renewable, current rates of use are often greater than the renewal rates, leading to degradation and declines in the future capacity of ecosystems to provide services. Dryland agricultural areas around the world are threatened by desertification. Freshwater supplies have been stressed by increasing withdrawals of groundwater and surface water, as well as by pollution. Marine fish harvest has declined since the late 1980s, and one quarter of marine fish stocks are overexploited or depleted. Despite growing global timber production, the condition of forests is diminishing. The observed rates of species extinction in modern times are as much as 1,000 times higher than the average observed for comparable taxonomic groups from the fossil record. These and many other losses have occurred in the course of using ecosystem services. The capacity of Earth's ecosystems to provide life-support services is changing rapidly, at a time when human pressures on ecosystems are also increasing. **The *Scenarios* volume explores the implications of different approaches for sustaining ecosystem services in the face of growing demand.** [S8, 9, 11, 14]

In order to plan for a changing and uncertain future, we must have tools for organizing extensive information about socioecological systems. Scenarios are such a tool. **Scenarios are plausible, provocative, and relevant stories about how the future might unfold. They can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations, though model projections may be used to quantify some aspects of the scenarios.** The process of building scenarios is intended to widen perspectives and illuminate key issues that might otherwise be either missed or dismissed. By offering insight into uncertainties and the consequences of current and possible future actions, scenarios support more informed and rational decision-making in situations of uncertainty. Scenarios are a powerful way of exploring possible consequences of different policies. They force us to state our assumptions clearly, enabling the consequences of those assumptions to be analyzed. Scenarios, and the products of scenarios, are not predictions. Rather, they explore consequences of different policy choices based on current knowledge of underlying socioecological processes. [S2, 3, 5]

This summary explores the scenarios, how we developed them, and what we have learned in the process. The first section describes the methods and the assumptions behind the scenarios. This is followed by four sections that explore the results for ecosystem services, trade-offs among ecosystem services, biodiversity, and human well-being. We conclude with a section describing research needs for improving future development of scenarios for ecosystem services and human well-being.

Developing the Millennium Ecosystem Assessment Scenarios

The MA scenarios assess the consequences of contrasting development paths for ecosystem services.

Because stresses on ecosystems are increasing, it is likely that large, costly, and even irreversible changes will become more common in the future. This will lead to reduced services provided by ecosystems or increased costs of maintaining services. Management that deliberately maintains resilience of ecosystems can reduce the risk of large, costly, or irreversible change.

Proactive or anticipatory management of ecosystems is particularly important under rapidly changing or novel conditions.

The MA developed a set of global scenarios to address the effects of different development paths on ecosystem services

and human well-being. The scenarios extend into the future from the situation described in the MA *Current State and Trends* volume. Three of the four pathways involve major positive actions taken to move toward sustainable development. The alternate pathways of the four contrasting scenarios illustrate many of the tools described in the MA *Policy Responses* volume. Although the scenarios focus on the global scale, many implications for regional and local ecosystems were examined. These provide a bridge to the MA *Multiscale Assessments* volume. **The contrasts among the global scenarios are designed to illuminate key risks and benefits of each pathway and to examine the interaction among drivers of ecosystem change, ecosystem services, and human well-being.**

The MA scenarios explore the potential consequences of alternate pathways to development, and they inform decision-makers about the consequences for ecosystem services. **The scenarios were designed to explore contrasting transitions of society as well as contrasting approaches to policies about ecosystem services.** (See Figure S1). We explore two kinds of transitions—one in which the world becomes increasingly globalized and another in which it becomes increasingly regionalized. Furthermore, we address two different approaches for governance and policies related to ecosystems and their services. In one case, management of ecosystems is reactive, and most problems are addressed only after they become obvious. In the other case, management of ecosystems is proactive, and policies deliberately seek to maintain ecosystem services for the long term.

Framed in terms of these contrasts, the four scenarios developed by the MA were named Global Orchestration (socially conscious globalization, with an emphasis on equity, economic growth, and public goods and with a reactive approach to ecosystems), Order from Strength (regionalized, with an emphasis on security and economic growth and with a reactive approach to ecosystems), Adapting Mosaic (regionalized, with an emphasis on proactive management of ecosystems, local adaptation, and flexible governance), and TechnoGarden (globalized, with an emphasis on using technology to achieve environmental outcomes and with a proactive approach to ecosystems). **The focus on ecosystem services and effects of ecosystems on human well-being distinguish the MA scenarios from previous global scenario exercises.** [S2, 3, 5, 8]

The future will represent a mix of approaches and consequences described in the scenarios, as well as events and innovations that have not yet been imagined. No scenario will match the future as it actually occurs. No scenario represents business as usual, although all begin from current conditions and trends. None of the MA scenarios represents a "best" or a "worst" path. Instead, they illustrate choices and trade-offs. There could be combinations of policies that produce significantly better, or worse, outcomes than any of the scenarios. Each of the scenarios begins in 2000 and ends in 2050. Each emphasizes different pathways of development. [S2] (See Box S1.)

Interviews with stakeholders and a literature review of major ecological dilemmas were used to identify focal questions, key uncertainties, and cross-cutting assumptions behind the scenarios. (See Figure S2). These focal questions, uncertainties, and assumptions, which are explored in more detail in the next paragraphs, were used to develop the four plausible, alternative futures. Scenarios were then constructed by working through the MA conceptual framework (indirect drivers, direct drivers,

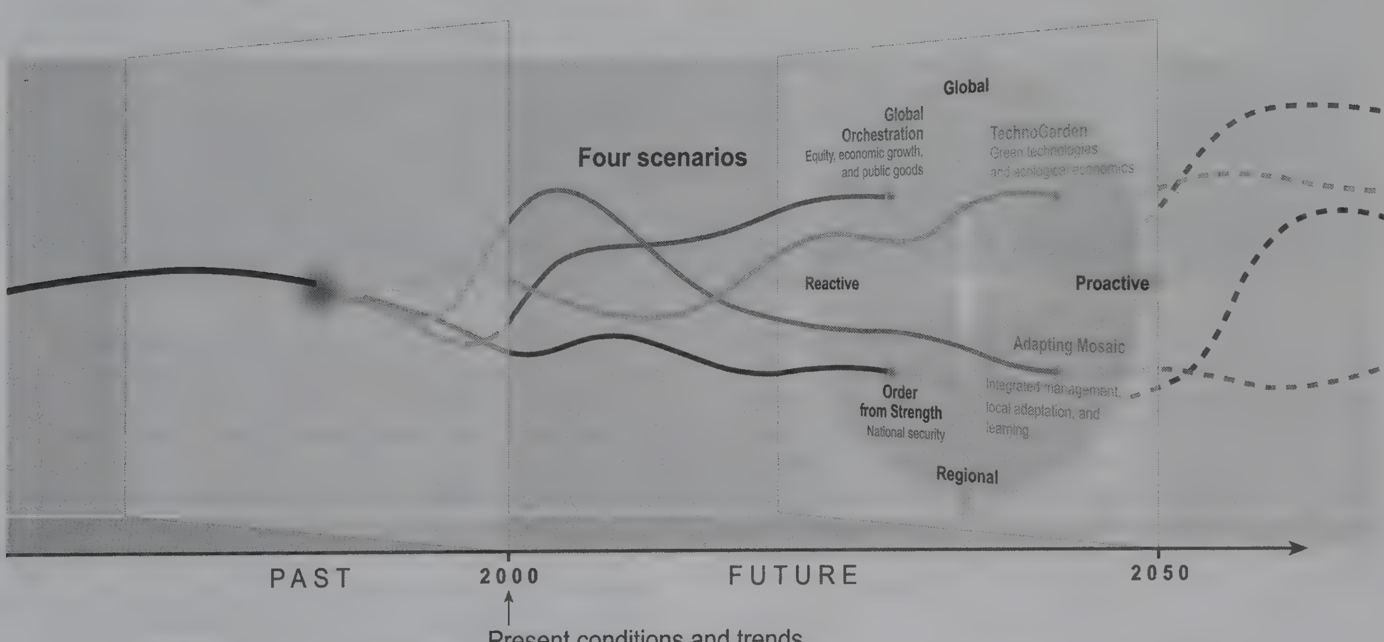


Figure S1. Millennium Ecosystem Assessment Scenarios: Plausible Future Development Pathways until 2050. The scenario differences are based on the approaches pursued toward governance and economic development (regionalized versus globalized) and ecosystem service management (reactive versus proactive).

BOX S1

Global Scenarios of the Millennium Ecosystem Assessment

The Global Orchestration scenario depicts a globally connected society in which policy reforms that focus on global trade and economic liberalization are used to reshape economies and governance, emphasizing the creation of markets that allow equitable participation and provide equitable access to goods and services. These policies, in combination with large investments in global public health and the improvement of education worldwide, generally succeed in promoting economic expansion and lift many people out of poverty into an expanding global middle class. Supranational institutions in this globalized scenario are well placed to deal with global environmental problems such as climate change and fisheries. However, the reactive approach to ecosystem management favored in this scenario makes people vulnerable to surprises arising from delayed action. While the focus is on improving human well-being of all people, environmental problems that threaten human well-being are only considered after they become apparent.

Growing economies, expansion of education, and growth of the middle class leads to demand for cleaner cities, less pollution, and a more beautiful environment. Rising income levels bring about changes in global consumption patterns, boosting demand for ecosystem services, including agricultural products such as meat, fish, and vegetables. Growing demand for these services leads to declines in other services, as forests are converted into cropped areas and pasture, and the services formerly provided by forests decline. The problems related to increasing food production, such as loss of wildlands, are remote to most people because they live in urban areas. These problems therefore receive only limited attention.

Global economic expansion expropriates or degrades many of the ecosystem services poor people once depended on for their survival. While economic growth more than compensates for these losses in some regions by increasing our ability to find substitutes for particular ecosystem services, in many other places it does not. An increasing number of people are affected by the loss of basic ecosystem services essential for human life. While risks seem manageable in some places, in other places there are sudden, unexpected losses as ecosystems cross thresholds and degrade irreversibly. Loss of potable water supplies, crop failures, floods, species invasions, and outbreaks of environmental pathogens increase in frequency. The expansion of abrupt, unpredictable changes in ecosystems, many with harmful effects on increasingly large numbers of people, is the key challenge facing managers of ecosystem services.

The Order from Strength scenario represents a regionalized and fragmented world concerned with security and protection, emphasizing primarily regional markets, and paying little attention to common goods. Nations see looking after their own interests as the best defense against economic insecurity, and the movement of goods, people, and information is strongly regulated and policed. The role of government expands as oil companies, water systems, and other strategic businesses are either nationalized or subjected to more state oversight. Trade is restricted, large amounts of money are invested in security systems, and technological change slows due to restrictions on the flow of goods and information. Regionalization exacerbates global inequality.

Agreements on global climate change, international fisheries, and the trade in endangered species are only weakly and haphazardly implemented, resulting in degradation of the global commons. Local problems often go unresolved, but major problems are sometimes handled by rapid disaster relief to at least temporarily resolve the immediate crisis. Many powerful countries cope with local problems by shifting burdens to other, less powerful countries, increasing the gap between rich and poor. In particular, natural resource–intensive industries are moved from wealthier nations to poorer and less powerful ones. Inequality increases considerably within countries as well.

Ecosystem services become more vulnerable, fragile, and variable in Order from Strength. For example, parks and reserves exist within fixed boundaries, but climate change crosses them, leading to the unintended extirpation of many species. Conditions for crops are often suboptimal, and the ability of societies to import alternative foods is diminished by trade barriers. As a result, there are frequent shortages of food and water, particularly in poor regions. Low levels of trade tend to restrict the number of invasions by exotic species; however, ecosystems are less resilient and invaders are therefore more often successful when they arrive.

In the Adapting Mosaic scenario, hundreds of regional ecosystems are the focus of political and economic activity. This scenario sees the rise of local ecosystem management strategies and the strengthening of local institutions. Investments in human and social capital are geared toward improving knowledge about ecosystem functioning and management, which results in a better

ecosystem services, and human well-being), using both qualitative and quantitative analyses. Qualitative and quantitative results were cross-checked at every stage. Quantitative results of one stage often affected qualitative results of the next stage, but qualitative results of one stage could not always be fed back into the existing numerical models. Finally, feedbacks from ecosystem services and human well-being played an important role in development of indirect and direct driver trajectories for the qualitative assessment. Such feedbacks are difficult to incorporate in the quantitative models, however. [S6]

Interviews identified many benefits, risks, opportunities, and threats from contrasting paths of globalization and governance for ecosystem management. While some advantages and disadvantages are clear, many have not been thoroughly explored, so we designed the scenarios to do that. The following bullets describe the theme of the scenarios, which were chosen to explore various tensions (the storyline most closely associated with each theme appears in parentheses at the end of the bullet). [S8, 11, 12, 13, 14]

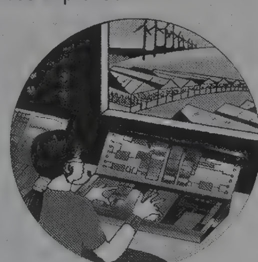
- Economic growth and expansion of education and access to technology increases the capacity to respond effectively when environmental problems emerge. However, if the focus on reducing poverty and increasing human and social capital overwhelms attention to the environment, and if proactive environmental policies are not pursued, there is increased risk of regional or even global interruptions in the provision of ecosystem services. Severe and irreversible declines in ecosystem services and human well-being may occur if we do not

understanding of resilience, fragility, and local flexibility of ecosystems. There is optimism that we can learn, but humility about preparing for surprises and about our ability to know everything about managing ecosystems.

There is also great variation among nations and regions in styles of governance, including management of ecosystem services. Many regions explore actively adaptive management, investigating alternatives through experimentation. Others use bureaucratically rigid methods to optimize ecosystem performance. Great diversity exists in the outcome of these approaches: some areas thrive, while others develop severe inequality or experience ecological degradation. Initially, trade barriers for goods and products are increased, but barriers for information nearly disappear (for those who are motivated to use them) due to improving communication technologies and rapidly decreasing costs of access to information.

Eventually, the focus on local governance leads to some failures in managing the global commons. Problems like climate change, marine fisheries, and pollution grow worse, and global environmental problems intensify. Communities slowly realize that they cannot manage their local areas because global and regional problems are infringing, and they begin to develop networks among communities, regions, and even nations to better manage the global commons. Solutions that were effective locally are adopted among networks. These networks of regional successes are especially common in situations where there are mutually beneficial opportunities for coordination, such as along river valleys. Sharing good solutions and discarding poor ones eventually improves approaches to a variety of social and environmental problems, ranging from urban poverty to agricultural water pollution. As more knowledge is collected from successes and failures, provision of many services improves.

The TechnoGarden scenario depicts a globally connected world relying strongly on technology and highly managed, often engineered ecosystems to deliver ecosystem services. Overall efficiency of ecosystem service provision improves but is shadowed by the risks inherent in large-scale human-made solutions and rigid control of ecosystems.



Technology and market-oriented institutional reform are used to achieve solutions to environmental problems. These solutions are designed to benefit both the economy and the environment. These changes co-develop with the expansion of property rights to ecosystem services, requiring people to pay for pollution they create and paying people for providing key ecosystem services through actions such as preservation of key watersheds. Interest in maintaining, and even increasing, the economic value of these property rights, combined with an interest in learning and information, leads to an increase in the use of ecological engineering approaches for managing ecosystem services.

Investment in green technology is accompanied by a significant focus on economic development and education, improving people's lives and helping them understand how ecosystems make their livelihoods possible. A variety of problems in global agriculture are addressed by focusing on the multifunctional aspects of agriculture and a global reduction of agricultural subsidies and trade barriers. Recognition of the role of agricultural diversification encourages farms to produce a variety of ecological services rather than simply maximizing food production. The combination of these movements stimulates the growth of new markets for ecosystem services, such as trade in carbon storage, and the development of technology for increasingly sophisticated ecosystem management. Gradually, environmental entrepreneurship expands as new property rights and technologies co-evolve to stimulate the growth of companies and cooperatives providing reliable ecosystem services to cities, towns, and individual property owners.

Innovative capacity expands quickly in lower-income nations. The reliable provision of ecosystem services as a component of economic growth, together with enhanced uptake of technology due to rising income levels, lifts many of the world's poor into a global middle class. While the provision of basic ecosystem services improves the well-being of the world's poor, the reliability of the services, especially in urban areas, is increasingly critical and increasingly difficult to ensure. Not every problem has succumbed to technological innovation. Reliance on technological solutions sometimes creates new problems and vulnerabilities. In some cases, we seem to be barely ahead of the next threat to ecosystem services. In such cases, new problems often seem to emerge from the last solution, and the costs of managing the environment are continually rising. Environmental breakdowns that affect large numbers of people become more common. Sometimes new problems seem to emerge faster than solutions. The challenge for the future will be to learn how to organize socioecological systems so that ecosystem services are maintained without taxing society's ability to implement solutions to novel, emergent problems.

address natural capital at the same time that we address social capital. (Global Orchestration)

- A focus on strong national security, which restricts the flow of goods, information, and people, coupled with a reactive approach to ecosystem management, can create great stress on ecosystems, particularly in poorer countries. While there may be some opportunities for conservation of biodiversity in wealthy or highly prized areas, in general a focus on security in wealthy nations leads to a loss of biodiversity in developing ones, as they often lack the resources to create measures for biodiversity protection. Without active, proactive management of ecosystems in a world like this, pressure on the environment increases; there is greater risk of large disturbances of ecosystem services and vulnerability to interruptions in provision of ecosystem services. Severe and irreversible declines in ecosystem services and human well-being may occur if we do not address ecosystem management where we live, in addition to focusing on reserves. (Order from Strength)
- When regional ecosystem management is proactive and oriented around adapting to change, ecosystem services become more resilient and society becomes less vulnerable to disturbances of ecosystem services. However, a regional focus can diminish attention to the global commons and exacerbates global environmental problems, such as climate change and declining oceanic fisheries. An adaptive approach may also have high initial costs and an initially slower rate of environmental improvement. If the focus on natural capital overwhelms attention to

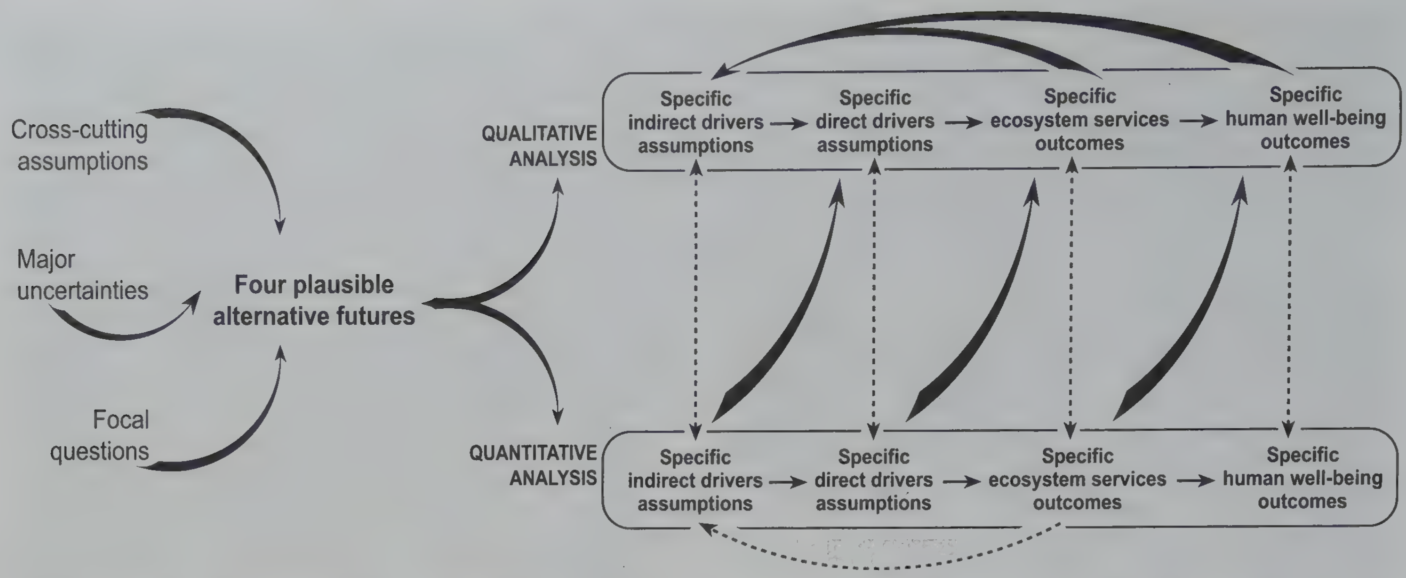


Figure S2. Flow Chart of MA Scenario Development. The focal questions, major uncertainties, and cross-cutting assumptions were used to develop basic ideas about four plausible alternative futures. These futures were elaborated using qualitative and quantitative methods. At each step, quantitative and qualitative results were cross-checked (the dotted lines between boxes). Quantitative results of each step were used to help determine qualitative results of the next step (diagonal arrows). Finally, feedbacks from qualitative ecosystem services and human well-being outcomes were used to re-evaluate assumptions about indirect drivers. This feedback procedure was also done in a qualitative way for some quantitative ecosystem services outcomes.

immediate human well-being, poverty alleviation may be somewhat slower. (Adapting Mosaic)

- Technological innovations and ecosystem engineering, coupled with economic incentive measures to facilitate their uptake, can lead to highly efficient delivery of provisioning ecosystem services. However, technologies can create new environmental problems, and in some cases the resulting disruptions of ecosystem services affect large numbers of people. In addition, efficient provision of ecosystem services may lead to greater demand for ecosystem services rather than less pressure on ecosystems to provide the same amount of service. (TechnoGarden)

The scenarios were also designed to explore key ecosystem management dilemmas. One such dilemma is that ecosystem management that neglects slow changes in resilience or vulnerability of ecosystems increases the susceptibility of ecosystems to large, rapid changes (*established but incomplete*). For example, government subsidies to agriculture have allowed farmers to continue harmful practices that eventually lead to larger losses of ecosystem services. When fish stocks decline, subsidies that sustain fishing effort prevent recovery of the stocks. Dependency on biocides can increase the vulnerability of agroecosystems to evolution of biocide-resistant pests. Because stresses on ecosystems are increasing, it is likely that large, costly, and even irreversible changes will become more common in the future. On the other hand, management that deliberately maintains resilience of ecosystems can reduce the risk of large, costly, or irreversible change (*established but incomplete*). The scenarios were constructed to explore this dynamic. [S5, 8, 9, 10]

Managing for surprise is another dilemma explored by the scenarios. **The MA scenarios differ in the frequency and magnitude of surprising changes in ecosystem services due to the management undertaken in each scenario, not due to any underlying ecological differences across the scenarios.** Each scenario implies different distributions of extreme events. (See Figure S3.) Examples of extreme events that affect ecosystem services are famines, technological failure of systems for quality control of food or water, massive floods, or serious and long-lasting heat waves or storms. The impact of an extreme event is driven by both the chance of an event happening and the vulnerability of people to the event. Extreme events

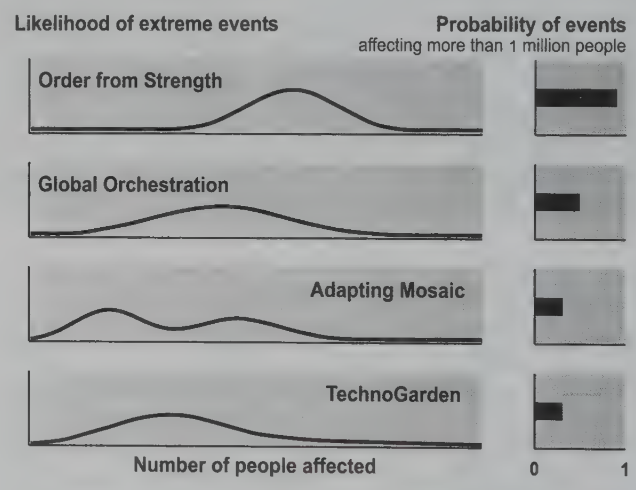


Figure S3. Probabilities of Extreme Events That Involve Ecosystem Services in MA Scenarios. Left column: Magnitude of extreme event (measured as the number of people affected) on the x-axis versus likelihood of events of a given magnitude, on the y-axis. Right column: Length of the bar indicates the annual probability of events that affect more than 1 million people.

affecting at least 1 million people are most common in Order from Strength and least common in Adapting Mosaic and TechnoGarden. [S5, 8]

Proactive or anticipatory management of ecosystems is particularly important under rapidly changing or novel conditions. (See Table S1.) Ecological surprises are inevitable. Currently well understood phenomena that were surprises of the past century include the ability of pests to evolve resistance to biocides, the contribution to desertification of certain types of land use, biomagnification of toxins, and the increase in vulnerability of ecosystems to eutrophication and invasion due to removal of keystone predators. While we do not know which surprises will arise in the next 50 years, we can be certain that some will occur. Restoration of ecosystems or ecosystem services following degradation is usually time-consuming and expensive, if possible at all, so anticipatory management to build resilient, self-maintaining ecosystems is likely to be extremely cost-effective. This is particularly true when conditions are changing rapidly, when conditions are variable, when control of ecosystems is limited, or when uncertainty is high. [S3]

The MA scenarios examine the need to develop and expand mechanisms of ecosystem management that avoid large ecosystem changes (by reducing stress on ecosystems), allow for the possibility of large ecosystem changes (by choosing reversible actions, experimenting cautiously, and monitoring appropriate ecological indicators), and increase the capacity of societies to adapt to large ecosystem changes (diversifying the portfolio of ecosystem services and developing flexible governance systems that adapt effectively to ecosystem change). [S3, 5]

Table S1. Costs and Benefits of Proactive Management as Contrasted with Reactive Ecosystem Management

	Proactive Ecosystem Management	Reactive Ecosystem Management
Payoffs	benefit from lower risk of unexpected losses of ecosystem services, achieved through investment in more-efficient use of resources (water, energy, fertilizer, and so on), more innovation of green technology, the capacity to absorb unexpected fluctuations in ecosystem services, adaptable management systems, and ecosystems that are resilient and self-maintaining do well under changing or novel conditions build natural, social, and human capital	avoid paying for monitoring efforts do well under smoothly or incrementally changing conditions build manufactured, social, and human capital
Costs	technological solutions can create new problems costs of unsuccessful experiments costs of monitoring some short-term benefits are traded for long-term benefits	expensive unexpected events persistent ignorance (repeating the same mistakes) lost option values inertia of less flexible and adaptable management of infrastructure and ecosystems loss of natural capital

Quantitative and qualitative results for drivers, ecosystem services, and human well-being are presented in Tables S2 and S3. Indirect drivers are generally the result of group consensus and represent our assumptions about the factors that underlie each of the scenarios. Direct drivers are most often model outcomes based on the indirect drivers. For example, model outcomes show carbon emissions to be quite high in the scenarios with high economic growth, especially if proactive climate policies are not adopted. (See Figure S4.) Ecosystem service outcomes are a mixture of model outcomes and qualitative estimates, both based on the direct drivers. Most human well-being outcomes, determined largely by the ecosystem services outcomes while taking into account other social conditions, such as wealth and education, are qualitative estimates.

For some drivers, ecosystem services, and human well-being indicators, quantitative projections were calculated using established, peer-reviewed global models. Quantifiable items include drivers such as economic growth and land use change and ecosystem services such as water withdrawals, food production, and carbon emissions. Other drivers (such as rates of technologic change), ecosystem services (particularly supporting and cultural services such as soil formation and recreational opportunities), and human well-being indicators (such as human health and social relations) for which there are no appropriate global models were estimated qualitatively. Qualitative estimates were the consensus professional judgment of experts in relevant fields.

We explored the status of quantitative modeling in at least nine areas relevant to the MA: land cover change, impacts of land cover changes on local climates, changes in food demand and supply, changes in biodiversity and extinction rates, impacts of changes in nitrogen/phosphorus cycles, fisheries and harvest, alterations of coastal ecosystems, and impacts on human health as well as the use of integrated assessment models that seek to piece together many different trends by predicting the consequences of changes in critical drivers. **All these models have weaknesses, but the alternative is no quantification whatsoever. Therefore, we used appropriate models with caution and explicitly stated our uncertainties.** Key uncertainties include limitations on the spatial or temporal resolution of input data, bias or random error in input data, poor or unknown correspondence between modeled mechanisms and natural processes (model uncertainty), lack of information about model parameters, limited experience with linking the different models, and the impossibility of predicting human events and individual choices (which may be altered by the forecasts themselves). [S4]

In general, models address incremental changes but fail to address thresholds, risk of extreme events,

Table S2. Main Assumptions about Indirect and Direct Driving Forces across the Scenarios [8, 9]

	Global Orchestration	Order from Strength: Industrial Nations[a]	Order from Strength: Developing Nations[a]	Adapting Mosaic	TechnoGarden
Indirect Driving Forces					
Demographics	high migration; low fertility and mortality levels; 2050 population: 8.1 billion	relatively high fertility and mortality levels (especially in developing countries); low migration, 2050 population: 9.6 billion		high fertility level; high mortality levels until 2010 then to medium by 2050; low migration, 2050 population: 9.5 billion	medium fertility levels, medium mortality; medium migration, 2050 population: 8.8 billion
Average income growth	high	medium	low	similar to Order from Strength but with increasing growth rates toward 2050	lower than Global Orchestration, but catching up toward 2050
GDP growth rates/ capita per year until 2050 (global)	1995–2020: 2.4% per year 2020–50: 3.0% per year	1995–2020: 1.4% per year 2020–50: 1.0% per year		1995–2020: 1.5% per year 2020–50: 1.9% per year	1995–2020: 1.9% per year 2020–50: 2.5% per year
Income distribution	becomes more equal	similar to today		similar to today, then becomes more equal	becomes more equal
Investments into new produced assets	high	medium	low	begins like Order from Strength, then increases	high
Investments into human capital	high	medium	low	begins like Order from Strength, then increases in tempo	medium
Overall trend in technology advances	high	low		medium-low	medium in general; high for environmental technology
International cooperation	strong	weak—international competition		weak—focus on local environment	strong
Attitude toward environmental policies	reactive	reactive		proactive—learning	proactive
Energy demand and lifestyle	energy-intensive	regionalized assumptions		regionalized assumptions	high level of energy-efficiency
Energy supply	market liberalization; selects least-cost options; intensified use of technology	focus on domestic energy resources		some preference for clean energy resources	preference for renewable energy resources and rapid technology change
Climate policy	no	no		no	yes, aims at stabilization of CO_2-equivalent concentration at 550 ppmv
Approach to achieving sustainability	economic growth leads to sustainable development	national-level policies; conservation; reserves, parks		local-regional co-management; common-property institutions	green-technology; eco-efficiency; tradable ecological property rights
Direct Driving Forces					
Land use change	global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	global forest loss faster than historic rate until 2025, near current rate after 2025; ~20% increase in arable land compared with 2000		global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	net increase in forest cover globally until 2025, slow loss after 2025; ~9% increase in arable land
Greenhouse gas emissions by 2050	CO_2: 20.1 GtC-eq CH_4: 3.7 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.7 GtC-eq	CO_2: 15.4 GtC-eq CH_4: 3.3 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.5 GtC-eq		CO_2: 13.3 GtC-eq CH_4: 3.2 GtC-eq N_2O: 0.9 GtC-eq other GHGs: 0.6 GtC-eq	CO_2: 4.7 GtC-eq CH_4: 1.6 GtC-eq N_2O: 0.6 GtC-eq other GHGs: 0.2 GtC-eq

Air pollution emissions	SO_2 emissions stabilize, NO_x emissions increase from 2000 to 2050	both SO_2 and NO_x emissions increase globally	SO_2 emissions decline; NO_x emissions increase slowly	strong reductions in SO_2 and NO_x emissions
Climate change	2.0°C in 2050 and 3.5°C in 2100 above pre-industrial	1.7°C in 2050 and 3.3°C in 2100 above pre-industrial	1.9°C in 2050 and 2.8°C in 2100 above pre-industrial	1.5°C in 2050 and 1.9°C in 2100 above pre-industrial
Nutrient loading	increase in N transport in rivers	increase in N transport in rivers	increase in N transport in rivers	decrease in N transport in rivers

[a] "Industrial " and "developing " refer to the countries at the beginning of the scenario; some countries may change categories by 2050.

Table S3. Outcomes for Ecosystem Services and Human Well-being in 2050 Compared with 2000 across the Scenarios [8, 9]

	Global Orchestration		Order from Strength		Adapting Mosaic		TechnoGarden	
	Industrial[a]	Developing[a]	Industrial[a]	Developing[a]	Industrial[a]	Developing[a]	Industrial[a]	Developing[a]
ECOSYSTEM SERVICES								
Provisioning Services								
Sufficient access to food	↑	↑	↔	↓	↔	↓	↑	↑
Fuel	↑	↑	↑	↑	↑	↑	↑	↑
Genetic resources	↔	↔	↓	↓	↑	↑	↔	↑
Biochemicals/Pharmaceuticals discoveries	↓	↑	↓	↓	↔	↔	↑	↑
Ornamental resources	↔	↔	↔	↓	↑	↑	↔	↔
Freshwater	↑	↑	↔	↓	↑	↓	↑	↔
Regulating Services								
Air quality regulation	↔	↔	↔	↓	↔	↔	↑	↑
Climate regulation	↔	↔	↓	↓	↔	↔	↑	↑
Water regulation	↔	↓	↓	↓	↑	↑	↔	↑
Erosion control	↔	↓	↓	↓	↑	↑	↔	↑
Water purification	↔	↓	↓	↓	↑	↑	↔	↑
Disease control: Human	↔	↑	↔	↓	↔	↑	↑	↑
Disease control: Pests	↔	↓	↓	↓	↑	↑	↔	↔
Pollination	↓	↓	↓	↓	↔	↔	↓	↓
Storm protection	↔	↓	↔	↓	↑	↑	↑	↔
Cultural Services								
Spiritual/religious values	↔	↔	↔	↓	↑	↑	↓	↓
Aesthetic values	↔	↔	↔	↓	↑	↑	↔	↔
Recreation and ecotourism	↓	↑	↓	↑	↓	↓	↑	↑
Cultural diversity	↓	↓	↓	↓	↑	↑	↓	↓
Knowledge systems (diversity and memory)	↔	↓	↓	↓	↑	↑	↔	↔
HUMAN WELL-BEING								
Material well-being	↑	↑	↑	↓	↔	↑	↑	↑
Health	↑	↑	↑	↓	↑	↑	↑	↑
Security	↑	↑	↓	↓	↑	↑	↑	↑
Social Relations	↔	↑	↓	↑	↑	↑	↓	↓
Freedom and Choice	↔	↑	↓	↓	↑	↑	↑	↑

[a] "Industrial " and "developing " refer to the countries at the beginning of the scenario; some countries may change categories by 2050.

Key: ↑ = increase in ecosystems' ability to provide the service, ↔ = ability of ecosystem to provide the service remains the same as in 2000, ↓ = decrease in ecosystems' ability to provide the service

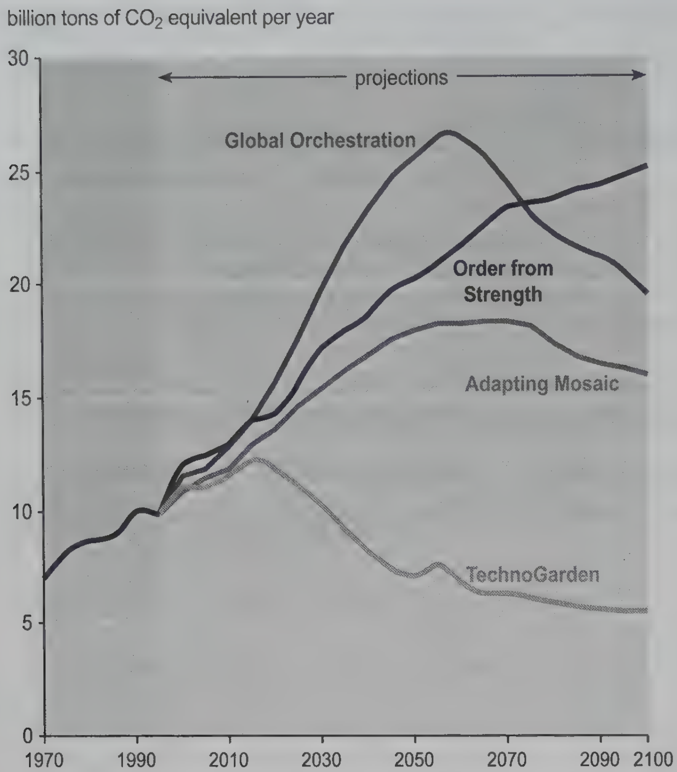


Figure S4. Total Greenhouse Gas Emissions in CO_2 Equivalents per Year versus Time in the MA Scenarios (equivalent emissions based on 100-year GWPs) [9]

or impacts of large, extremely costly, or irreversible changes in ecosystem services. We addressed these phenomena qualitatively by considering the risks and impacts of large but unpredictable ecosystem changes in each scenario. Some ecosystem services and aspects of human well-being could not be quantified and could be assessed only qualitatively. [S4]

The Future of Ecosystem Services

The capacity of ecosystems to provide services in the future is jeopardized by rates of use that exceed rates of renewal and by degradation of regulating ecosystem services.

Although the current flow of many ecosystem services to people has increased, the status of many ecosystems, including stocks of provisioning ecosystem services, has shifted to degraded conditions (*well established*). These include losses in marine fish stocks and dryland agriculture; emergence of diseases that threaten plants, animals, and humans; deterioration of water quality in fresh waters and coastal oceans; and regional climate changes and increased climate variability. Such shifts are likely to increase in the future (*established but incomplete*). The impact of unexpected ecosystem changes depends on the intensity of stress on ecosystems as well as societal expectations about reliability of ecosystem services and the capacity of societies to cope with changes in the provision of ecosystem services. [S8, 9, 13]

For some components of the future state of human-ecosystem interactions, all four scenarios make similar projections:

- Demand for provisioning services, such as food, fiber, and water, increases due to growth in population and economies (*high certainty*).
- Food security remains out of reach for many people, and child malnutrition will be difficult to eradicate even by 2050 (*low to medium certainty*), despite increasing food supply under all four scenarios (*medium to high certainty*) and more diversified diets in poor countries (*low to medium certainty*). (See Figure S5.)
- Vast changes with great geographic variability occur in freshwater resources and their provisioning of ecosystem services in all scenarios. (See Figure S6.) Climate change will lead to increased precipitation over more than half of Earth's surface and this will make more water available to society and ecosystems (*medium certainty*). However, increased precipitation is also likely to increase the frequency of flooding in many areas (*high certainty*). Increases in precipitation will not be universal, and climate change will also cause a substantial decrease in precipitation in some areas, with an accompanying decrease in water availability (*medium certainty*). These areas could include highly populated arid regions such as the Middle East and Southern Europe (*low to medium certainty*). While water withdrawals decrease in most industrial countries, water withdrawals and wastewater discharges are expected to increase enormously in Africa and some other developing regions, and this will intensify their water stress and overshadow the possible benefits of increased water availability (*medium certainty*).
- The services provided by freshwater resources (such as aquatic habitat, fish production, and water supply for households, industry, and agriculture) deteriorate severely in developing countries under the scenarios that are reactive to environmental problems. Less severe but still important declines are expected in the scenarios that are more proactive about environmental problems (*medium certainty*).
- Growing demand for fish and fish products leads to an increasing risk of a major and long-lasting decline of

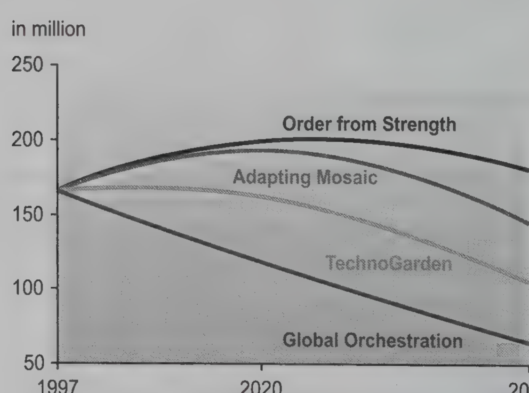


Figure S5. Number of Malnourished Children in Developing Countries over Time in MA Scenarios [9]

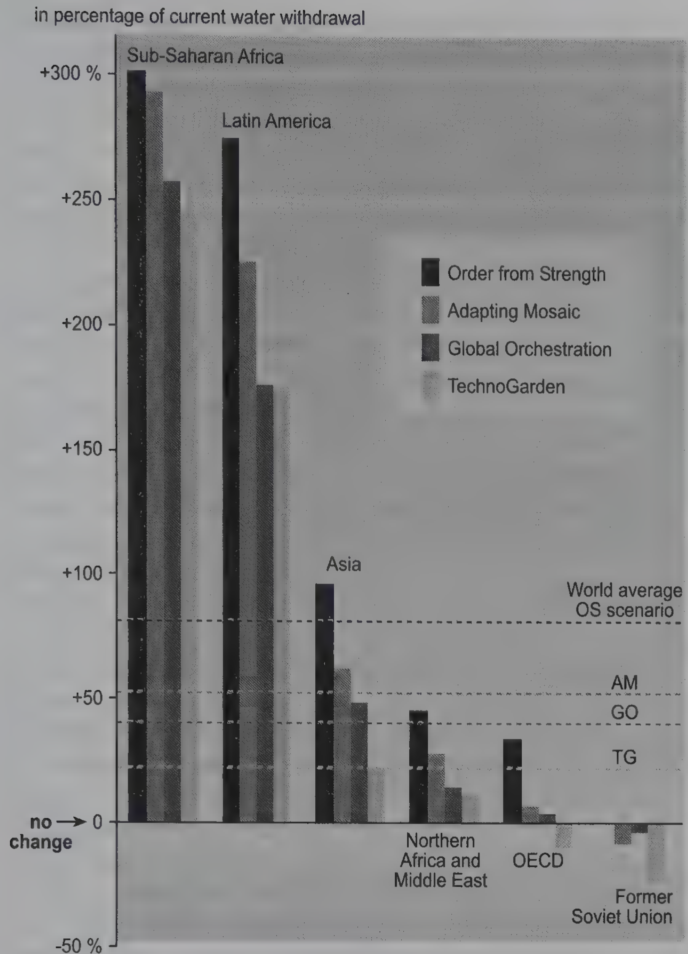


Figure S6. Change in Water Withdrawals from 2000 to 2050 in MA Scenarios, Globally and for Six Groups of Nations [9]

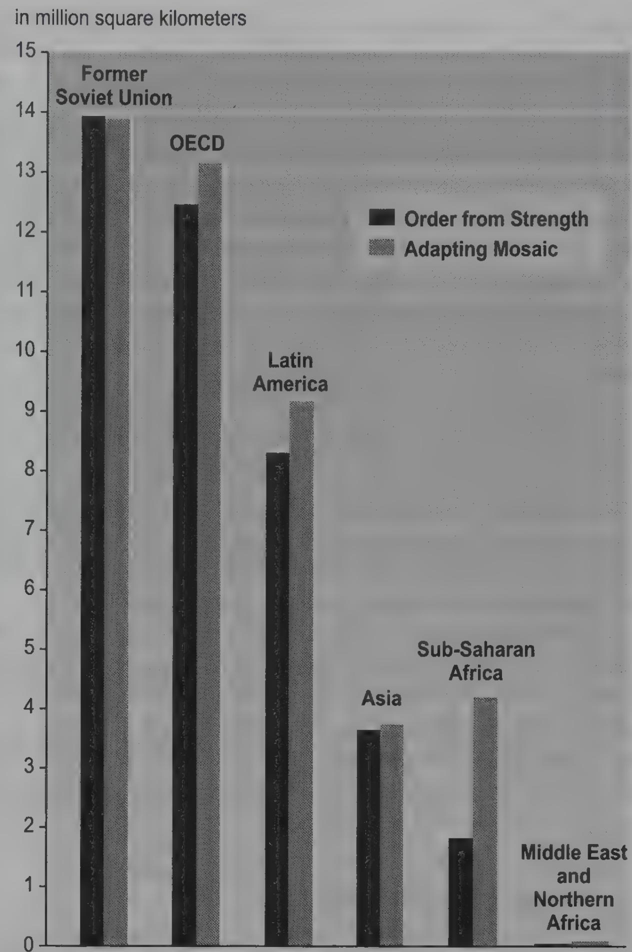


Figure S7. Forest Area in 2050 in Adapting Mosaic and Order from Strength Scenarios in Six Groups of Nations. Forest area is the net result of losses of pre-existing forest and establishment of new forest on land that was formerly used for something else [9]

regional marine fisheries (*medium to high certainty*). Aquaculture cannot relieve this pressure so long as it continues to rely heavily on marine fish as a food source.

Land use change is expected to continue to be a major driver of changes in the provision of ecosystem services up to 2050 (*medium to high certainty*) [S9]. The scenarios indicate (*low to medium certainty*) that 10–20% of current grassland and forestland will be lost between now and 2050. This change occurs primarily in low-income and arid regions. (See Figure S7.) The provisioning services associated with affected biomes (such as genetic resources, wood production, and habitat for terrestrial biota) will also be reduced. The degree to which natural land is lost differs among the scenarios. Order from Strength has the greatest land use changes, with large increases in both crop and grazing areas. The two proactive scenarios, TechnoGarden and Adapting Mosaic, are the most land-conserving ones because of increasingly efficient agricultural production, lower meat consumption, and lower population increases. Existing wetlands and the services they provide (such as water purification) are faced with increasing risk in some areas due to reduced runoff or intensified land use in all scenarios.

Threats to drylands are multiscale—ranging from global climate change to local pastoral practices. In addition, dryland ecosystem services are particularly vulnerable to substantial and persistent reductions in ecosystem services driven by climate change, water stress, and intensive use. For example, sub-Saharan Africa is projected to expand water withdrawals rapidly to meet needs for development. Under some scenarios, this causes a rapid increase in untreated return flows to freshwater systems, which could endanger public health and aquatic ecosystems (*medium certainty*). Expansion and intensification of agriculture in this area may lead to loss of natural ecosystems and higher levels of surface and groundwater contamination. Loss of ecosystem services related to these changes could undermine the future provision of ecosystem services in this region, eventually leading to increased poverty. **Global institutions to address dryland problems (such as desertification) need to consider responses at multiple scales, such as mitigation of climate change, technological development, and trade and resource transfers that foster local adaptation.** [S14]

In our scenarios, continued population growth, improving economic conditions, and climate change over the next decades exert additional pressure on land resources and pose additional risk of desertification in dryland regions. **Subsi-**

dizing food production and water development in vulnerable drylands can have the unintended effect of increasing the risk of even larger breakdowns of ecosystem services in future years. Local adaptation and conservation practices can mitigate some losses of dryland ecosystem services, although it will be difficult to reverse trends toward loss of food production capacity, water supplies, and biodiversity in drylands. [S14]

Threats of wetland drainage and conversion, with adverse impacts on capacity of ecosystems to provide adequate supplies of clean water, increased in all scenarios. Reductions in trade that accompany greater regionalization can increase pressure on agricultural land and water withdrawals. To some extent, these adverse effects can be mitigated by economic growth, technology, or regional adaptive management. However, economic growth without proactive ecosystem management can increase the risk of large disturbances of water supplies, water quality, and other aquatic resources such as fish and wildlife. [S14]

Terrestrial ecosystems are currently a net sink of CO_2 at a rate of 1.2 (+/− 0.9) gigatons of carbon per year (*high certainty*). They thereby contribute to the regulation of climate. But the scenarios indicate that the future of this service is uncertain. Deforestation is expected to reduce the carbon sink. Proactive environmental policies can maintain a larger terrestrial carbon sink. [S9]

The Future of Biodiversity

Present goals for reduced rates of biodiversity loss will be difficult to achieve because of changes in land use that have already occurred and ongoing stresses from climate change and nutrient enrichment.

Ecosystem management practices that maintain response diversity, functional groups, and trophic levels while mitigating chronic stress are more likely to increase the supply of ecosystem services and decrease the risk of large losses of ecosystem services than practices that ignore these factors.

The scenarios indicate that present goals for reduced rates of biodiversity loss, such as the 2010 targets of the Convention of Biological Diversity, will be difficult to achieve because of changes in land use that have already occurred, ongoing stresses from climate change, and nutrient enrichment. In all scenarios, projections indicate significant negative impacts on biodiversity and its related ecosystem services. However, these scenarios were not designed to optimize the path for preserving biodiversity. Negative impacts on biodiversity can be reduced by proactive steps to, for example, decrease the rate of land conversion, integrate conservation practices with landscape planning, restore ecosystems, and mitigate emissions of nutrients and greenhouse gasses. It is important to note that decreasing rates of land conversion may impair our ability to meet increased demands for food or other ecosystem services. [S10, 14]

Significant decline of ecosystem services can occur from species loss even if species do not become globally extinct. Some terrestrial ecosystem services will be lost (*very certain*) as local native populations are extirpated (become locally extinct). Examples include loss of cultural services when a culturally important forest species is extirpated, loss of supporting services when pollinator species are extirpated, and loss of provisioning services when an important medicinal plant becomes locally extinct. [S10]

Production and resilience of ecosystems are often enhanced by genetic and species diversity as well as by spatial patterns of landscapes and temporal cycles (such as successional cycles) with which species evolved. Within ecosystems, species and groups of species perform functions that contribute to ecosystem processes and services in different ways. Diversity among functional groups increases the flux of ecosystem processes and services (*established but incomplete*). For example, plant species that root at different depths, that grow or flower at different times of the year, and that differ in seed dispersal and dormancy act together to increase ecosystem productivity.

Within functional groups, species respond differently to environmental fluctuations. This response diversity derives from variation in the response of species to environmental drivers, heterogeneity in species distributions, differences in ways that species use seasonal cycles or disturbance patterns, or other mechanisms. Response diversity increases the chance that ecosystems will contain species or functional groups that become important for maintaining ecosystem processes and services in future changed environments (*medium certainty*). **Ecosystem management practices that maintain response diversity, functional groups, and trophic levels while mitigating chronic stress will increase the supply and resilience of ecosystem services and decrease the risk of large losses of ecosystem services** (*established but incomplete*). [S5]

Habitat loss in terrestrial environments is projected to lead to decline in local diversity of native species in all four scenarios by 2050 (*high certainty*). (See Figure S8.) Loss of habitat results in the immediate extirpation of local populations and the loss of the services that these populations provided. [S10]

Decreases in river flows from water withdrawals and climate change (decreases occur in 30% of all major river basins) are projected to result in loss of species under all scenarios (*low certainty*). Rivers that are forecast to lose fish species are concentrated in poor tropical and sub-tropical countries, where the needs for human adaptation are most likely to exceed governmental and societal capacity to cope. The current average GDP in countries with diminishing river flows is about 20% lower than in countries whose rivers are not drying. [S10]

Habitat loss will eventually lead to global extinctions as species approach equilibrium with the remnant habitat. Although there is *high certainty* that this will happen eventually, the time to equilibrium is *very uncertain*, especially given continued habitat loss through time. Between 10% and 15% of vascular plant species present in 1970 were lost across the four scenarios when species numbers reached equilibrium with reduced habitat (*low certainty*). This may be an under-

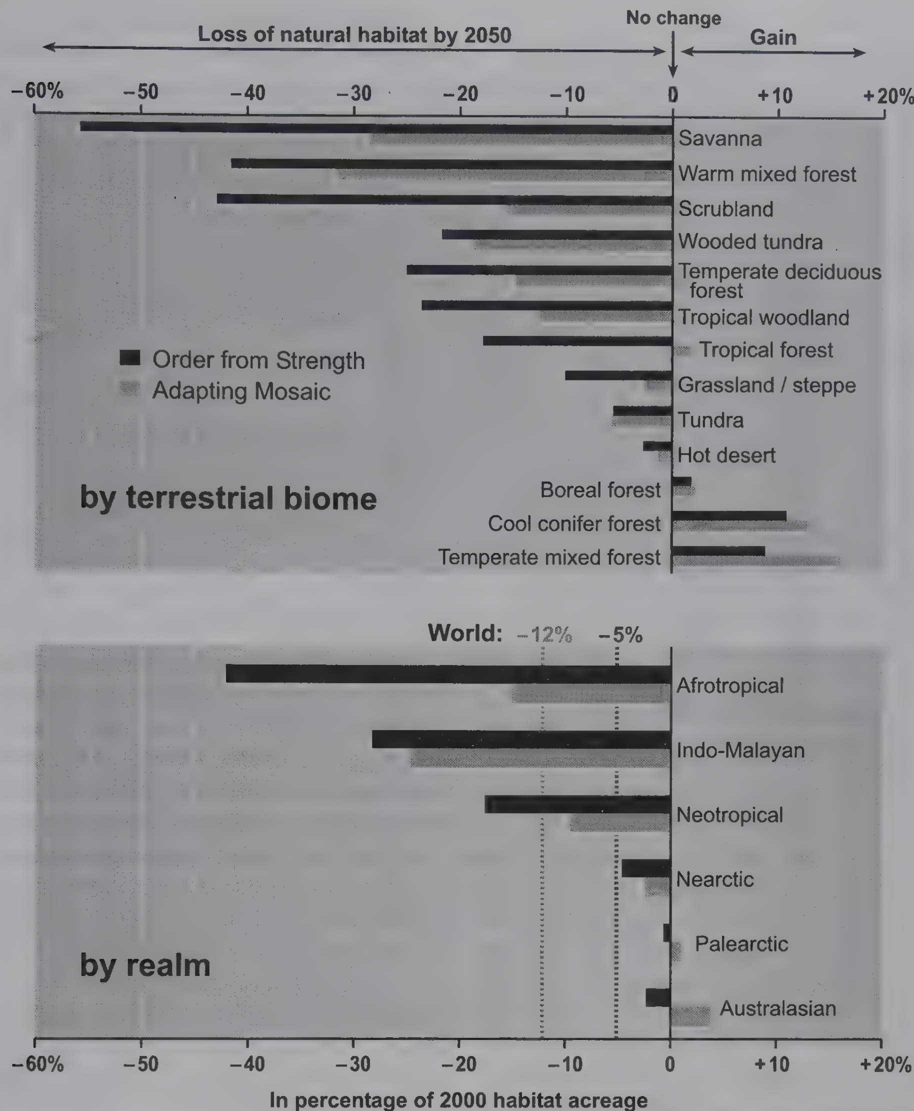


Figure S8. Loss or Gain of Natural Habitat from 1970 to 2050 in Adapting Mosaic and Order from Strength Scenarios. Habitat changes are indicated by biome and by biogeographic realm. [9, 10]

estimate because it addresses only those changes due to habitat loss and does not consider the effects of other stressors such as climate change or nutrient deposition. Time lags between habitat reduction and extinction provide a precious opportunity for humans to rescue those species that otherwise may be on a trajectory toward extinction. [S10]

Trade-offs among Ecosystem Services

Increasing the flow of provisioning services often leads to reductions in supporting, regulating, and cultural ecosystem services. This may reduce the future capacity of ecosystems to provide services.

Building understanding about how ecosystems provide services will increase society's capacity to avert large disturbances of those services or to adapt to them rapidly when they do occur.

Trade-offs exist in all of the MA scenarios between food and water and between food and biodiversity. Each scenario takes a slightly different approach to addressing these trade-offs. By comparing these approaches and their outcomes, we can learn about managing trade-offs. [S12]

- **In all four MA scenarios, application of fertilizers, including manure, in excess of crop needs caused large nutrient flows into fresh waters and estuaries** (*high certainty*). (See Figure S9.) This overenrichment of water causes serious declines in ecosystem services (food, recreation, fresh water, and biodiversity) provided by aquatic ecosystems. There are possibilities for mitigating these trade-offs through technological enhancements such as agricultural efficiency (in the use of land, water, and fertilizers) and through productivity-enhancing, resource-conserving technologies, which combine natural capital conservation with yield improvement techniques.
- **In all four MA scenarios, conversion of land to agricultural uses for food production reduced biodiversity.** Clearing diverse land cover for crop production reduces biodiversity by eliminating local populations.

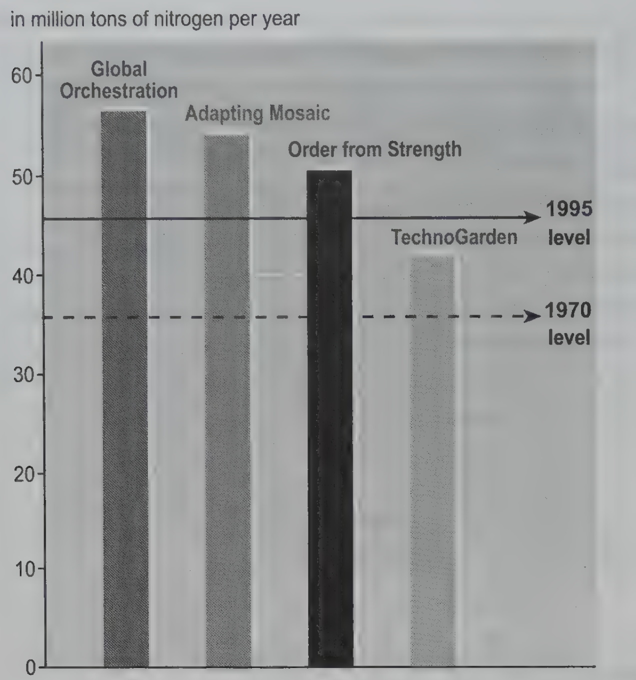


Figure S9. Global River Nitrogen Export in 2030 in MA Scenarios. Reference lines show global river nitrogen export in 1970 and 1995.

Removing water from lakes and rivers for use can reduce aquatic biodiversity because less aquatic habitat is available. There are possibilities for mitigating these trade-offs through agricultural land management that explicitly maintains biodiversity or through more efficient use of water.

- **In all four MA scenarios, use of water for irrigation of crops reduced the availability of water for other uses, such as household or industrial use or the maintenance of other ecosystem services.** Although water is a renewable resource, the amount available in any one place at any one time is finite. Thus, excessive use of water for irrigation can restrict the amount of water for other important uses.

All scenarios show the general tendency of management to focus intensely on increasing the availability of provisioning services, which often leads to reductions in the provision of supporting, regulating, and cultural ecosystem services. (See Figure S10.) Efforts to increase the short-term provision of services typically reduce the capacity of ecosystems to provide the full array of services in the future. This vulnerability can be difficult to detect because ecosystems often exhibit threshold behavior that can mask declines in regulating and supporting services until a collapse occurs. Such trade-offs have far-reaching consequences for maintaining ecosystem functioning in the long term. For example, decisions about fertilizer use in the 1960s are still affecting water quality in the twenty-first century.

Scenarios in which long-term consequences of trade-offs are not taken into consideration exhibit the largest risk of declines in supporting and regulating services (such as climate change and biodiversity loss). Scenarios with a proactive approach to ecosystem management via flexible ecosystem governance mechanisms and learning or technological innovations are more likely to sustain ecosystem services in the future. [S12]

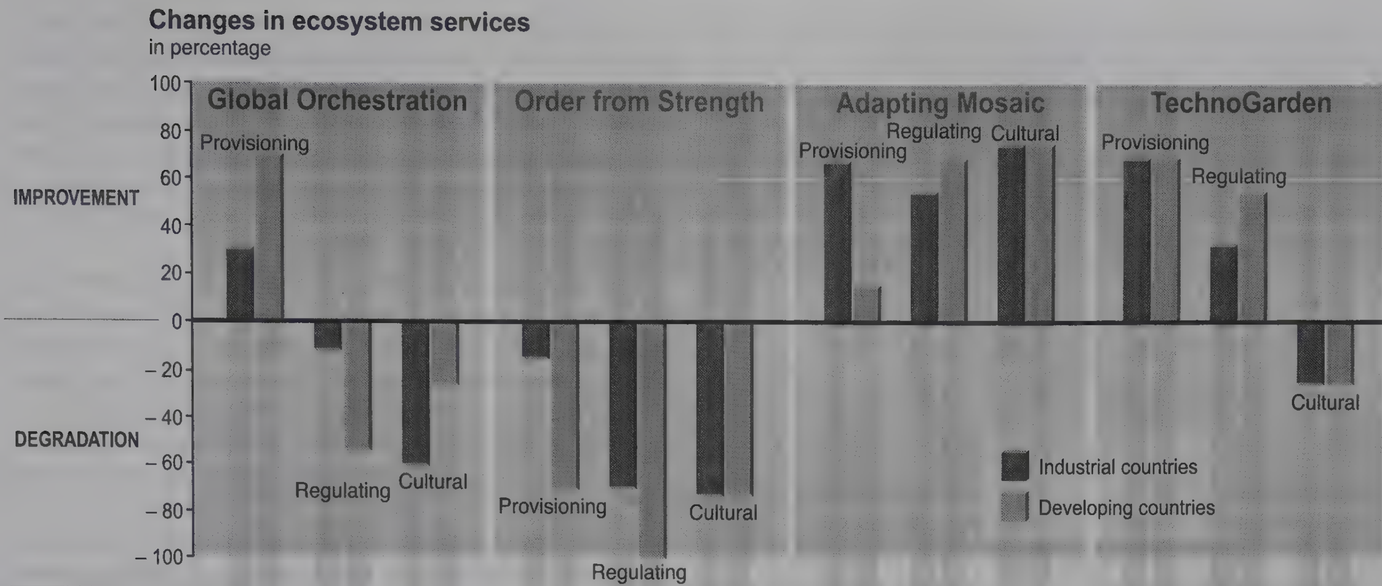
At every scale, there are opportunities for combining advantageous approaches to achieve synergistic benefits. For example, actions to preserve marine fish species have been shown to make coral reefs more resistant to the pressures associated with declines in other species or excess nutrients. Actions to preserve local fisheries have been shown to have positive benefits on human well-being through enhancing social interactions and networking among fishers in the region. Advantages can be found by combining techniques from each of the scenarios. For example, combining the advantages of green technology (TechnoGarden) with fairer markets (Global Orchestration) and flexible ecosystem management that encourages local creativity (Adapting Mosaic) may lead to improvements in ecosystem services and human well-being beyond those found in any individual scenario. [S12]

In the scenarios in which monitoring was a focus, societies built an understanding of large changes in ecosystem services that increased their capacity to anticipate and avert large disturbances of ecosystem services or to adapt to them more rapidly if they did occur. In the scenarios in which monitoring was not done and policies that anticipate the possibility of large breakdowns in ecosystem services were not implemented (Global Orchestration and Order from Strength), societies faced increased risk of large impacts from unexpected disruptions of ecosystem services. The greatest risks of large, unfavorable ecological changes arise in dryland agriculture, marine fisheries, quality of fresh and coastal marine waters, disease emergence, and regional climate change. [S8, 12, 14]

The Future of Human Well-being

Attempts to improve human well-being that do not actively take ecosystems into account can cause unintended but rapid, severe, and persistent degradation of ecosystem services.

Most of the 2015 targets established for the Millennium Development Goals were not achieved in the MA scenarios. The scenarios also indicate that some strategies for achieving goals such as poverty reduction and hunger reduction quickly could increase pressures on ecosystems, thereby compromising the ability to continue progress toward these goals in the future and undermining progress toward the MDG of environmental sustainability. Although the MA scenarios were not designed to chart an optimal path to meeting the MDGs, they provide useful information about plausible paths. Attempts to meet the MDGs by 2015, which will largely involve increased use of provisioning ecosystem services, may lead to ecosystem degradation and reductions in regulating and supporting services that undermine future ecosystem capacity to supply provisioning services. This



Number of services	GO Prov. Ind.	GO Prov. Dev.	GO Reg. Ind.	GO Reg. Dev.	GO Cult. Ind.	GO Cult. Dev.	OS Prov. Ind.	OS Prov. Dev.	OS Reg. Ind.	OS Reg. Dev.	OS Cult. Ind.	OS Cult. Dev.	AM Prov. Ind.	AM Prov. Dev.	AM Reg. Ind.	AM Reg. Dev.	AM Cult. Ind.	AM Cult. Dev.	TG Prov. Ind.	TG Prov. Dev.	TG Reg. Ind.	TG Reg. Dev.	TG Cult. Ind.	TG Cult. Dev.
Enhanced	3	4	0	1	0	1	1	1	0	0	0	1	4	3	5	6	4	4	4	4	4	6	1	1
No change	2	2	8	2	3	2	3	0	3	0	2	0	2	1	4	3	0	0	2	2	4	2	2	2
Degraded	1	0	1	6	2	2	2	5	6	9	3	4	0	2	0	0	1	1	0	0	1	1	2	2

Figure S10. Net Changes in Availability of Provisioning, Regulating, and Cultural Ecosystem Services by 2050 in MA Scenarios for Industrial and Developing Countries. The y-axis is the net percentage of ecosystem services enhanced or degraded. For example, 100% degradation of the six provisioning ecosystem services would mean that all of these were degraded in 2050 relative to 2000, while 50% enhancement could mean that three were enhanced and the other three were unchanged, or that four were enhanced, one was degraded, and the other two were unchanged. The data used to calculate the y-axis are presented beneath the figure.

degradation may increase the risk of regime shifts and other surprises that seriously undermine human well-being. [S14]

Ecosystem services are essential for human well-being. However, the relationship between human well-being and ecosystem services is discontinuous. Above some threshold, a marginal increase in ecosystem services contributes only slightly to human well-being, but below that threshold, a small decrease in ecosystem services can substantially reduce it. [S11]

Across the dimensions of human well-being, each scenario yields a different package of gains, losses, and vulnerabilities for different regions and populations. (See Figure S11.) In our scenarios, actions that focused on improving the lives of the poor by reducing barriers to international flows of goods, services, and capital tended to lead to the most improvement for those who are currently the most disadvantaged. Health and social relations improve, but human vulnerability to ecological surprises is high.

Globally integrated approaches that focused on technology and property rights for ecosystem services generally improved human well-being in terms of health, security, social relations, and material needs. When those same technologies were used globally, however, local culture was lost or undervalued. High levels of trade lead to more rapid spread of emergent diseases, somewhat reducing the gains in health in all areas. Locally focused, learning-based approaches led to the largest improvements in social relations, but with variability by region. Order from Strength, which focuses on reactive policies in a regionalized world, has the least favorable outcomes for human well-being, as the global distribution of ecosystem services and human resources that underpin human well-being are increasingly skewed. [S11]

Toward Future Assessments of Ecosystem Services

The future capacity of ecosystems to provide services is often determined by feedbacks at multiple scales. Future projects on ecosystem service scenarios should explicitly nest or link assessments at several scales from the beginning.

Active adaptive ecosystem management (experimentation with monitoring and analysis to learn more-sustainable management methods) could greatly improve outcomes for ecosystem services and human well-being.

In considering multiple aspects of ecosystem services and feedbacks with human well-being, this assessment is the first of its kind. Lessons learned from the MA suggest many opportunities to improve the development of ecosystem service scenarios in the future.

The future capacity of ecosystems to provide services is often determined by feedbacks at multiple scales. Future projects on ecosystem service scenarios should explicitly nest or link assessments at several scales from the beginning. This innovation would pro-

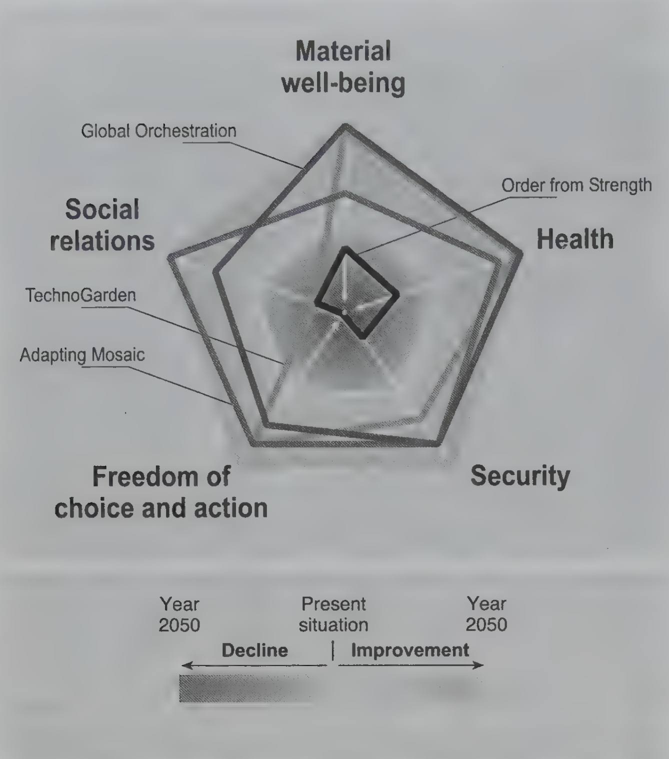


Figure S11. Changes in Components of Human Well-being in 2050 in MA Scenarios. The pentagon in the middle represents the situation in 2000. Moving outward from that indicates an improvement in that component of human well-being in that scenario by the year 2050. Moving inward from the pentagon indicates a decline in that aspect of human well-being since 2000.

vide decision-makers with information that links local, national, regional, and global futures of ecosystem services directly. In addition, future projects should allow more time for iterations between qualitative and quantitative assessments of the storylines. This additional work would improve the harmonization of qualitative and quantitative assessments and allow for a more diverse set of simulations to address risks and regime shifts. [S4, 6, 13]

Active adaptive ecosystem management (experimentation with monitoring and analysis to learn more-sustainable management methods) could greatly improve outcomes for ecosystem services and human well-being. Existing assessment models for most ecosystem services do not account for effects of active adaptive management at local to regional scales. Thus most of our projections of ecosystem services represent outcomes in the *absence* of local-to-regional adaptive change. Actively adaptive management could significantly improve the outcomes relative to the projections presented here. (See the MA *Policy Responses* volume.) [S4, 5, 13]

There are important gaps between the processes depicted in the MA conceptual framework and the existing capacity of ecosystem modeling. Major elements of the conceptual framework that are not well addressed by models include the effects of changes in ecosystems on flows of ecosystem services and the effects of changes in ecosystem services on changes in human well-being. In addition, existing models focus mainly on a subset of provisioning and regulating ecosystem services, largely neglecting cultural and supporting ecosystem services. Cultural ecosystem services, together with the other ecosystem services, play a critical role in adaptive responses and changes in human attitudes and behaviors toward nature. [S4, 13]

The underlying chapters in this volume list many specific needs for improved models. Models are needed to address thresholds and the risk of large, costly, or irreversible changes in ecosystem services. There is emerging understanding that the diversity of species response and the heterogeneity of landscapes affect the resilience of ecosystem services. This important feedback needs to be incorporated in ecosystem service models. [S4, 5, 9, 10, 13]

Future projects on ecosystem service scenarios should allow more time for assessing decision-maker needs at the outset of the project and should include decision-makers in the scenarios development team. Differences among disciplines in core beliefs about functioning of the global system are a crucial uncertainty that is addressed in the scenarios. Better interdisciplinary communication would make it easier to understand and assimilate these differences in future scenario exercises. Finally, communication of scenarios requires development of synthetic graphics, nontechnical narratives, and nontechnical illustrations. Future projects on ecosystem service scenarios should allocate more time for creation of these important communication and outreach products. [S13]

Synthesis

Future conditions of ecosystem services could be worse or better than in the present, depending on policy choices.

None of the MA scenarios represents an optimal outcome. A selected mix of policies from several scenarios may yield better outcomes than any single scenario.

The Millennium Ecosystem Assessment scenarios show that the condition of ecosystem services in the future could be significantly worse or better than in the present. Scenarios that improve the condition of ecosystem services and human well-being involve substantial changes in policy. Examples include:

- major investments in public goods and poverty reduction, together with elimination of harmful trade barriers and subsidies (Global Orchestration);
- widespread use of actively adaptive ecosystem management and investment in education (Adapting Mosaic); and
- significant investments in technologies to use ecosystem services more efficiently, along with widespread inclusion of ecosystem services in markets (TechnoGarden).

Although examples of all these policies are known from the world of today, such policies are not widespread at the present time.

The MA scenarios were not designed to determine optimal policies for any specific locale, nation, international bloc, or Earth as a whole. Different combinations of policies may produce significantly better results than any of the scenarios presented here. Successful hybrid policies may capitalize on the advantages of several scenarios while avoiding the risks. For example, combining the local-learning approach of Adapting Mosaic with the global coordination and technological advances of TechnoGarden may capitalize on the benefits of both scenarios while avoiding the loss of cultural services found in TechnoGarden and the global commons problems found in Adapting Mosaic.

Chapter 4

Policy Responses: Response Options and Strategies

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Introduction

The Millennium Ecosystem Assessment examines the consequences of changes to ecosystem services for human well-being. It assesses the conditions and trends in ecosystems and their services, explores plausible scenarios for the future, and assesses alternative response options. The assessment of the Condition and Trends Working Group affirms that, in the aggregate, changes to ecosystems have contributed to substantial gains in human well-being over the past centuries: people are better nourished and live longer and healthier lives than ever before, incomes have risen, and political institutions have become more participatory. However, these gains have been achieved at growing costs, including the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people. Persistent and significant local, national, and regional disparities in income, well-being, and access to ecosystem services continue to exist. The assessment of the Scenarios Working Group shows that the degradation of ecosystem services could grow significantly worse during the first half of this century and represents a barrier to achieving the Millennium Development Goals.

The question arises: What kind of action can we take? What policies can be developed and implemented by societies to enable them to move in chosen directions? In this report, we define "responses" to encompass the entire range of human actions, including policies, strategies, and interventions, to address specific issues, needs, opportunities, or problems related to ecosystems, ecosystem services, and human well-being. Responses may be institutional, economic, social and behavioral, technological, or cognitive in nature. Response strategies are designed and undertaken at local, regional, or international scales within diverse institutional settings. This report assesses how successful various response strategies have been and identifies the conditions that have contributed to their success or failure. Additionally, it derives lessons that can be applied to the design of future responses.

The MA conceptual framework (MA 2003) posits that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being. (See Chapter 1, Box 1.2.) Direct and indirect drivers operate at different spatial, temporal, and organizational scales. Responses affect the direct and indirect drivers of change in ecosystems and thereby the services derived from ecosystems. In this framework, human–ecosystem interactions are dynamic processes and, as a result, drivers and responses co-evolve over time. Expansion of cultivated systems, for instance, was initially a response to the growing demand for food. Over time, this expansion of cultivation became a driver of change altering other ecosystem services, particularly as a result of habitat conversion, use of water for irrigation, and the excessive use of nutrients. A full assessment of the effectiveness of various responses must thus include the examination of the historical and contemporary contexts within which interactions between drivers and responses developed. The choice of the most effective set of response options needs to be informed not just by the impact of the response on a particular driver, but also by the interactions among different drivers themselves.

The effectiveness and impact of any response strategy depends furthermore on the interactions between the people who initiate the response and others who have a stake in the outcomes at local, regional, and global levels. Strategies initiated at the global level, such as through international conventions, for example, may have consequences on ecosystem services and human well-being at the local level.

The Responses Working Group assessed a wide range of responses and interventions undertaken by different decision-makers in many different economic, social, and institutional settings. In the sections that follow, this summary describes several key characteristics of successful responses, discusses methods for choosing responses, and reviews some of the more promising or effective responses. It also discusses some of the barriers to implementing promising responses; one barrier that deserves particular emphasis involves the limited number of trained people in many countries who are able to analyze response options and to develop and implement programs of action to address these problems. This assessment demonstrates the tremendous scope for actions that can help to enhance human well-being while conserving ecosystems; but without investment in the necessary human and institutional capacity, many countries will not be able to effectively pursue these options.

Characteristics of Successful Responses

Responses to environmental problems tend to be more successful when: a) there is effective coordination among the different levels of decision-making; b) transparent participatory approaches are used; c) the potential trade-offs and synergies among response strategies and their outcomes are factored into their design; and d) considerations of impacts on ecosystems and the potential contributions of ecosystem services are mainstreamed in economic policy and development planning.

Coordination across Sectors and across Scales

Effective action to address problems related to ecosystem services requires improved coordination across sectors and scales. **[See especially R5, 17, 19]**

Almost any action affecting an ecosystem has consequences for many different services provided by that ecosystem. For example, a response designed to enhance the production of one ecosystem service, such as crop production, could harm other services such as water quality, fisheries production, or flood control. These trade-offs cannot be adequately addressed through traditional sectoral management approaches. Moreover, they cannot be adequately addressed through actions undertaken at a single scale, whether international, national, or local. Effective ecosystem manage-

ment thus requires effective coordination, both among governmental institutions directly responsible for the environment and between those institutions and other sectors. [R17]

Coordination among International Institutions

The cooperation among multilateral environmental agreements has improved in recent years, but considerable scope remains to increase the coordination and consistency among their objectives and actions. [R17] To date, however, there has been relatively little effective coordination between MEAs and the politically stronger international economic and social institutions such as the World Bank (except in its role as an implementing agency of the Global Environment Facility), the International Monetary Fund, and the World Trade Organization. Despite their profound influence on the environment, economic and trade-related agreements have shown minimal commitment to environmental issues; neither have the poverty reduction strategies prepared by countries for the World Bank. Given the central importance of ecosystem services in achieving many Millennium Development Goals (in particular, the goals and targets related to poverty, hunger, disease, children's health, water, and environmental sustainability), the MDG process could in principle provide a means to better incorporate the environment into these other sectors, but little progress has yet been observed. [R19]

Coordination across Decision-making Levels

International agreements are more likely to be translated into national policy if they include precise obligations, sanctions for violation, and monitoring provisions, and if they provide financial assistance for national implementation. While most MEAs meet some of these criteria, relatively few have sanctions for violation; in almost all cases, there is considerable scope for the agreements to be strengthened if the criteria were met more effectively. [R17] For example, financial mechanisms such as the Global Environment Facility enable assistance to be provided through some ecosystem-related MEAs, but across the board these agreements would be more effective if greater assistance were available. Similarly, the Convention on Biological Diversity, the Convention to Combat Desertification, and the Ramsar Wetlands Convention could be strengthened if countries assumed additional outcome-focused obligations in addition to the more common planning and reporting obligations. The CBD, for example, has now established a specific outcome-focused target—the "2010 Target" to significantly slow the rate of biodiversity loss—but this target is not binding on individual countries.

Some steps have been taken by the ecosystem-focused MEAs to promote greater national implementation. For example, the national biodiversity strategies and action plans form a central implementation mechanism of the CBD and have resulted in some action at the national and local levels.[R5] The CCD has encouraged the development of national action programs to combat desertification; 50 of these programs are now receiving international funding. While the CBD national biodiversity strategies and the CCD national action programs have stimulated and guided some actions and policy reforms, their primary impact has been within the environmental sector; they have been less effective in influencing action in other sectors. The overall effectiveness of the implementation of these and other MEAs could be strengthened if these planning processes were more effectively integrated into other processes such as decentralization and land reform, which generally have major effects on land use and desertification.

In general, international agreements dealing with ecological resources tend to be less successful than those concerning defense or trade because of the less obvious nature of reciprocal benefits to contracting parties, the major driving force in other agreements. Success of international legal instruments depends on the perception of the need for longer term cooperation. The design of the agreement and the manner in which the agreement was negotiated both play a role. Given the complexity of some negotiating processes and the lack of resources to enable the full participation of many developing countries in negotiations, some countries face serious challenges in ensuring adequate representation of their interests and perspectives in international agreements; this in turn undermines the effectiveness of the agreements. [R17] Clearly, there exists an urgent need to augment developing-country capacity to participate in international negotiations.

Coordination at National and Sub-national Levels

At national and sub-national levels, effective responses to ecosystem degradation are constrained by the same weakness of cross-sectoral coordination and even coordination within the environmental sector. The implementation of many environmental conventions at a national level, for example, could be strengthened through more effective coordination among the national offices responsible for implementing different international agreements. More generally, at the national and sub-national levels successful response interventions often involve situation-driven integration across decision-making agencies. This type of integration tends to be found in situations where communities and lower level governments are given management and decision-making flexibility within broad enabling frameworks.

Participation and Transparency

***Insufficient participation and transparency in planning and decision-making have been major barriers to the design and implementation of effective responses.* [R3, 4, 5, 7, 14, 15, 17]**

The importance of stakeholder participation is now widely recognized, although generally poorly implemented, at the international scale, as well as at the national and local scales. Although stakeholder participation can result in a slower and more costly process, it creates ownership in the policy being developed, commitment to successful implementation, and increased societal acceptance of the policy. Among international conventions, for example, the CBD states "management should be decentralized to the lowest appropriate level, and boundaries for management shall be de-

fined by indigenous and local peoples, among others." The 1999 Ramsar Convention Conference of Parties adopted guidelines for the inclusion of local and indigenous people in the management of Ramsar wetlands. The problems associated with inadequate stakeholder participation are most apparent in the area of biodiversity conservation. Because local people are de facto the primary resource managers in most regions, working with local communities is essential to conserving biodiversity in the longer term. The establishment of protected areas, for example, is more effective when local communities have "bought in" to the protected area and have alternative livelihood opportunities or receive direct payments so that they are not harmed by creation of the proteced area. [R5] This often requires the establishment of protected areas designed to support multiple uses of natural and cultural resources. Bottom-up decision-making processes rooted in a local and site-specific context have also enabled the negotiation of water agreements to become a catalyst for peace and cooperation. Note, for instance, that nation states belonging to very different political persuasions confirm water treaties such as the Nile treaty and the Indus Waters treaty. [R7]

Important as stakeholder participation is, the financial costs and time needed for elaborate stakeholder processes can sometimes outweigh the benefits. Moreover, there is also the risk that "participation" can be co-opted into what are, at their core, centrally determined plans. This kind of "centralized decentralization" may well lead to the exclusion of disadvantaged groups even though they have been "consulted" in the decision process. Often this is the consequence of policies that do not take into account differences among stakeholders in preexisting situations. Examples are found in the watershed programs and the water user associations in India.

The introduction of participatory approaches in settings where people are not accustomed to such approaches must be accompanied by capacity-building among stakeholders if it is to succeed. The capacity created in this way must also be sustained. Key interventions include both public education and steps taken to strengthen social networks in order to facilitate the inclusion of all relevant forms of knowledge and information, including local and indigenous knowledge, in decision-making.

For participatory approaches to succeed, the stakeholders involved need access to information on both the resources being managed and the decision-making process. Effective monitoring, assessment, and reporting is therefore a key to success in allocating ecosystem services and implementing response options. Given the heterogeneity, constant change, and site-specific characteristics of ecosystem services and the human institutions through which they are managed, a fundamental but often overlooked need is for an independent and transparent process of assessment. Monitoring and assessment are critical components of pro-active adaptive management, as they can provide the feedback necessary to develop and continually improve implementation strategies as new information becomes available, constraints are identified, and enabling institutional structures put in place. Although considerable debate continues about the most effective mechanisms for stakeholder involvement in decision-making processes, all approaches agree on the same core elements: acknowledge the limits of human understanding, recognize knowledge gaps explicitly, give special consideration to irreversible changes, and evaluate the impacts of decisions as they unfold.

Trade-offs and Synergies

***Trade-offs and synergies among human well-being, ecosystems, and ecosystem services are the rule rather than the exception and this implies that informed choices must be made to achieve the best possible outcomes.* [R5, 6, 7, 8, 11, 13, 15, 16, 17]**

The following categories of trade-offs are involved in managing ecosystem services:

- *Trade-offs between the present and future.* For example, some technologies developed to increase food production, such as the replacement of traditional cultivars with high yielding varieties or the excessive application of fertilizers and pesticides, have reduced the capacity of land and water systems to provide food in the future. [R6] Similarly, some resource management practices yield economic benefits in the present, but defer costs to the future. Forest harvest, for example, provides immediate economic returns but may result in future costs in the form of degraded water quality or increased frequency of floods.
- *Trade-offs among ecosystem services.* The majority of response strategies have given priority to increasing the allocation of provisioning services, such as food production and water supply, often at the expense of regulating and cultural ecosystem services. For example, water has been impounded to enable increased irrigation and increased food production, but this reduces downstream water supplies, harms freshwater biodiversity, and degrades some cultural and recreational benefits provided by free-flowing rivers.
- *Trade-offs among constituents of human well being.* Responses are often directed at improving the material well-being constituent of human well-being to the neglect of other constituents of human well-being such as health and security. For example, increased use of pesticides can increase the production of food, but harm the health of farmworkers and consumers.
- *Trade-offs among stakeholders.* Ecosystems and their services are used differently by different groups of stakeholders: the needs of vulnerable groups are often marginalized in this process. For example, large scale commercial exploitation of forests for timber harvest often comes at the expense of the use of forests by local communities as a source of non-wood forest products. [R8] Similarly, the conversion of mangrove forests to shrimp aquaculture benefits the farmers who have resources to invest in aquaculture operations, but harms the local fisherfolk who depend on capture fisheries associated with the mangroves.

Although negative trade-offs are common, positive synergies are also possible, and responses can be identified that create synergies and help in achieving multiple objectives.

The long-term success of conservation strategies in areas where local people are dependent on the use of biological resources, for example, depends on meeting the needs of these communities. The exact nature of the synergy is more easily identified in specific ecological and societal contexts through an appropriate understanding of linkages between ecosystems and human well-being. Similarly, among the growing number of people who face health problems associated with obesity, reducing consumption of food would benefit both human health and reduce demand for ecosystem services.

Some potential and emerging synergies can only be realised if enabling institutions are created. For example, afforestation, reforestation, improved forest, cropland and rangeland management and agroforestry provide a range of opportunities to increase carbon sequestration. Similarly, slowing deforestation provides an opportunity to reduce carbon emissions. Such activities have the potential to sequester about 10 to 20% of projected fossil emissions up to 2050. [R13] However, only a small part of this potential can be delivered with the institutions, technologies, and financial arrangements now in place. A large number of these issues remain undecided and prevent the use of forestry as a carbon management option.

Mainstreaming

***The quantity and quality of ecosystem services available are often determined to a greater extent by macroeconomic, trade, and other policies than by policies within the environmental sector itself.* [R5, 6, 8, 17, 19]**

Some of the most significant drivers of change in ecosystem services and their use originate outside the sectors that have responsibility for the management of ecosystem services. For example, the availability of fish in coastal waters can be strongly influenced by government policies related to crop production or food price supports, since this will influence the amount of fertilizer and water used in crop production and hence the potential harmful impacts associated with nutrient pollution or changes in river flows. Similarly, trade policies can have significant impacts on forest product industries and thus on the management of forests. Indeed, this assessment finds that policies outside the forest sector are often more important than policies within the sector in determining the social and ecological sustainability of forest management. While inappropriate policies in other sectors can harm ecosystem services, changes in those policies can often also provide one of the most effective means for improving managment of ecosystem services. For example, reforms to the Common Agricultural Policy in Europe to incorporate environmental dimensions could significantly reduce pressures on some ecosystem services. [R6]

In general, potential threats to ecosystem services and the potential contributions of ecosystem services to economic development and poverty reduction are not taken into account in development plans and trade policies. Very few macroeconomic responses to poverty reduction have considered the importance of sound management of ecosystem services as a mechanism to meet the basic needs of the poorest. The poverty reduction strategies that many developing countries are now preparing for the World Bank and other donors can be most effective if they include an emphasis on the links between ecosystems and human well-being, but few of the strategies incorporate these issues. [R17] More generally, the failure to incorporate considerations of ecosystem management in the strategies being pursued to achieve many of the eight Millennium Development Goals will undermine the sustainability of any progress that is made toward the goals and targets associated with poverty, hunger, disease, child mortality, and access to water, in particular. [R19]

Choosing Responses

Decisions affecting ecosystems and their services can be improved by changing the processes used to reach those decisions. [R18]

The context of decision-making about ecosystems is changing rapidly. The new challenge to decision-making is to make effective use of information and tools in this changing context in order to improve the decisions. At the same time, some old challenges must still be addressed. The decision-making process and the actors involved influence the intervention chosen. Decision-making processes vary across jurisdictions, institutions, and cultures. Even so, this assessment has identified the following elements of decision-making processes related to ecosystems and their services that tend to improve the decisions reached and their outcomes for ecosystems and human well-being:

- use the best available information, including considerations of the value of both marketed and nonmarketed ecosystem services;
- ensure transparency and the effective and informed participation of important stakeholders;
- recognize that not all values at stake can be quantified, and thus quantification can provide a false objectivity in decision-making processes that have significant subjective elements;
- strive for efficiency, but not at the expense of effectiveness;
- consider equity and vulnerability in terms of the distribution of costs and benefits;
- ensure accountability and provide for regular monitoring and evaluation; and
- consider cumulative and cross-scale effects and, in particular, assess trade-offs across different ecosystem services.

A wide range of tools can assist decision-making concerning ecosystems and their services. [R3, 4] The use of decision-making methods that adopt a pluralistic perspective is particularly pertinent, since these techniques do not give undue weight to any particular viewpoint. Examples of tools that can assist decision-making at a variety of scales, including global, sub-global, and local, include:

- *Deliberative tools (which facilitate transparency and stakeholder participation)*. These include neighborhood forums, citizens' juries, community issues groups, consensus confer-

ences, electronic democracy, focus groups, issue forums, and ecosystem service user forums.

- *Information-gathering tools (which are primarily focused on collecting data and opinions).* Examples of information-gathering tools include citizens' research panels, deliberative opinion polls, environmental impact assessments, participatory rural appraisal, and rapid rural appraisal.
- *Planning tools (which are typically used to evaluate potential policy options).* Some common planning tools are consensus participation, cost-benefit analysis, multicriteria analysis, participatory learning and action, stakeholder decision analysis, trade-off analysis, and visioning exercises.

Some of these methods are particularly well-suited for decision-making in the face of uncertainties in data, prediction, context, and scale. [R4] Such methods include cost-benefit or multicriteria analyses, risk assessment, the precautionary principle, and vulnerability analysis. (See Table R1.) All these methods have been able to support optimization exercises, but few of them have much to say about equity. Cost-benefit analysis can, for example, be modified to weight the interests of some people more than others. The discount rate can be viewed, in long-term analyses, as a means of weighting the welfare of future generations; and the precautionary principle can be expressed in terms of reducing the exposure of certain populations or systems whose preferential status may be the result of equity considerations. Multicriteria analysis was designed primarily to accommodate optimization across multiple objectives with complex interactions, but this can also be adapted to consider equity and threshold issues at national and sub-national scales.

Scenario-building exercises provide one way to cope with many aspects of uncertainty, but our limited understanding of ecological and human response processes shrouds any individual scenario in its own characteristic uncertainty. [R4] The development of a set of scenarios provides a useful means to highlight the implications of alternative assumptions about critical uncertainties related to the behavior of human and ecological systems. In this way, they provide one means to cope with many aspects of uncertainty in assessing responses. The relevance, significance, and influence of scenarios ultimately depend on the assumptions made in their development. At the same time, though, there are a number of reasons to be cautious in the use of scenarios. First, individual scenarios represent conditional projections based on specific assumptions. Thus to the extent that our understanding and representation of the ecological and human systems represented in the scenarios is limited, specific scenarios are characterized by their own uncertainty. Second, there is uncertainty in translating the lessons derived from scenarios developed at one scale—say, global—to the assessment of responses at other scales—say, sub-national. Third, scenarios often have hidden and hard-to-articulate assumptions. Fourth, environmental scenarios have tended to more effectively incorporate state-of-the-art natural science modeling than social science modeling.

Effective management of ecosystems requires coordinated responses at multiple scales. [R15, 17] Responses that are successful at a small scale are often less successful at higher levels due to constraints in legal frameworks and government institutions that prevent their success. In addition, there appear to be limits to scaling up, not only because of these higher-level constraints, but also because interventions at a local level often address only direct drivers of change rather than indirect or underlying ones. For example, a local project to improve livelihoods of communities surrounding a protected area in order to reduce pressure on it, if successful, may increase migration into buffer zones, thereby adding to pressures. Cross-scale responses may be more effective at addressing the higher-

Table R1. Applicability of Decision Support Methods and Frameworks

Key: ++ = direct application of the method by design
+ = possible application with modification or (in the case of uncertainty) the method has already been modified to handle uncertainty
– = weak but not impossible applicability with significant effort

Method	Optimization	Equity	Thresholds	Uncertainty	Scale of Application: Micro	Scale of Application: National	Scale of Application: Regional and Global
Cost-benefit Analysis	+	+	–		√	√	√
Risk Assessment	+	+	++	++	√	√	√
Multicriteria Analysis	++	+	+	+	√	√	
Precautionary Principle*	+	+	++	++	√	√	√
Vulnerability Analysis	+	+	++	+	√	√	

*The precautionary principle is not strictly analogous to the other analytical and assessment methods but still can be considered a method for decision support. The precautionary principle prescribes how to bring scientific uncertainty into the decision-making process by explicitly formalizing precaution and bringing it to the forefront of the deliberations. It posits that significant actions (ranging from doing nothing to banning a potentially harmful substance or activity, for instance) may be justified when the degree of possible harm is large and irreversible.

level constraints and leakage problems and simultaneously tackling regional and national as well as local-level drivers of change. Examples of successful cross-scale responses include some co-management approaches to natural resource management in fisheries and forestry and multistakeholder policy processes.

Active adaptive management can be a particularly valuable tool for reducing uncertainty about ecosystem management decisions. [R17] The term "active" adaptive management is used here to emphasize the key characteristic of the original concept (which is frequently and inappropriately used to mean "learning by doing"): the design of management programs to test hypotheses about how components of an ecosystem function and interact, in order to reduce uncertainty about the system more rapidly than would otherwise occur. Under an adaptive management approach, for example, a fisheries manager might intentionally set harvest levels either lower or higher than the "best estimate" in order to gain information more rapidly about the shape of the yield curve for the fishery. Given the high levels of uncertainty surrounding coupled socioecological systems, the use of active adaptive management is often warranted.

Promising Responses for Ecosystem Services and Human Well-being

Past actions to slow or reverse the degradation of ecosystems have yielded significant benefits, but these improvements have generally not kept pace with growing pressures and demands. Although most ecosystem services assessed in the MA are being degraded, the extent of that degradation would have been much greater without responses implemented in past decades. For example, more than 100,000 protected areas (including strictly protected areas such as national parks as well as areas managed for the sustainable use of natural ecosystems such as timber harvest or wildlife harvest) covering about 11.7% of the terrestrial surface have now been established. These protected areas play an important role in the conservation of biodiversity and ecosystem services, although important gaps remain in their distribution and management, particularly in marine and freshwater systems. Many protected areas lack adequate resources for management. Protected areas will not be completely effective until they are fully integrated into an ecosystem or landscape approach to management. [R5]

An effective set of responses to ensure the sustainable management of ecosystems would address the indirect and direct drivers that lead to the degradation of ecosystem services and overcome a range of barriers. The barriers to be overcome include:

- inappropriate institutional and governance arrangements, including the presence of corruption and weak systems of regulation and accountability;
- market failures and the misalignment of economic incentives;
- social and behavioral factors, including the lack of political and economic power of some groups (such as poor people, women, and indigenous groups) who are particularly dependent on ecosystem services or harmed by their degradation;
- underinvestment in the development and diffusion of technologies that could increase the efficiency of use of ecosystem services and reduce the harmful impacts of various drivers of ecosystem change; and
- insufficient knowledge (as well as the poor use of existing knowledge) concerning ecosystem services and management, policy, technological, behavioral, and institutional responses that could enhance benefits from these services while conserving resources.

All these barriers are compounded by weak human and institutional capacity related to the assessment and management of ecosystem services, underinvestment in the regulation and management of their use, lack of public awareness, and lack of awareness among decision-makers of the threats posed by the degradation of ecosystem services and the opportunities that more sustainable management of ecosystems could provide.

The MA assessed 78 response options for ecosystem services, integrated ecosystem management, conservation and sustainable use of biodiversity, waste management, and climate change. Many of these options hold significant promise for conserving or sustainably enhancing the supply of ecosystem services; a selected number of promising responses that address the barriers just described are discussed here. (The full list of response options is presented in Appendix R1.) These responses in turn often require that the proper enabling conditions are in place. (See Box R1.) The stakeholder groups that would need to take decisions to implement each re-

BOX R1

Enabling Conditions for Designing Effective Responses

Some examples of conditions that must be met in order to design and implement some of the response options identified in this assessment include:

- *supportive insurance and financial markets* are needed to ensure that economic value of ecosystem services is taken into account;
- *better information on who benefits and is harmed by changes in specific ecosystem services* is needed to enable the establishment of effective systems of payments for ecosystem services;
- *greater involvement of concerned stakeholders in decision-making* is required to ensure transparency and effective functioning of regulatory mechanisms;
- *appropriate forms of property rights* (mostly common property arrangements) need to be established to encourage private-public or community-state partnerships for resource conservation;
- *innovative partnerships among different knowledge-based institutions* need to be established to foster the integration of local and indigenous knowledge in decision-making processes; and
- *human and institutional capacity for assessing and acting on assessments* needs to be enhanced for decision-makers to have access to information they need concerning the management of ecosystem services.

sponse are indicated as follows: G for government, B for business and industry, and N for nongovernmental organizations and other civil society organizations (including community-based and indigenous peoples' organizations and research institutions).

Institutions and Governance

Changes in institutional and environmental governance frameworks are sometimes required in order to create the enabling conditions for effective management of ecosystems; in other cases, existing institutions could meet these needs but face significant barriers. [R2, 7, 11, 12, 15, 17] Many existing institutions at both the global and the national level have the mandate to address the degradation of ecosystem services but face a variety of challenges in doing so related to the need for greater cooperation across sectors and the need for coordinated responses at multiple scales (see the discussion above on Characteristics of Successful Responses). However, since a number of the issues identified in this assessment are recent concerns and were not specifically taken into account in the design of today's institutions, changes in existing institutions and the development of new ones may sometimes be needed, particularly at the national scale.

In particular, existing national and global institutions are not well designed to deal with the management of open access resources, a characteristic of many ecosystem services. Issues of ownership and access to resources, rights to participation in decision-making, and regulation of particular types of resource use or discharge of wastes can strongly influence the sustainability of ecosystem management and are fundamental determinants of who wins and who loses from changes in ecosystems. Corruption—a major obstacle to effective management of ecosystems—also stems from weak systems of regulation and accountability.

Promising interventions include:

- *Development of institutions that devolve (or centralize) decision-making to meet management needs while ensuring effective coordination across scales* (G, B, N). Problems of ecosystem management have been exacerbated by both overly centralized and overly decentralized decision-making. For example, highly centralized forest management has proved ineffective in many countries, and efforts are now being made to move responsibility to lower levels of decision-making either within the natural resources sector or as part of broader decentralization of governmental responsibilities. At the same time, one of the most intractable problems of ecosystem management has been the lack of alignment between political boundaries and units appropriate for the management of ecosystem goods and services. Downstream communities may not have access to the institutions through which upstream actions can be influenced; alternatively, downstream communities or countries may be stronger politically than upstream regions and may dominate control of upstream areas without addressing upstream needs.
- *Development of institutions to regulate interactions between markets and ecosystems* (G). The potential of policy and market reforms to improve ecosystem management is often constrained by weak or absent institutions. For example, the potential of the Clean Development Mechanism established under the Framework Convention on Climate Change to provide financial support to developing countries in return for greenhouse gas reductions, which would realize climate and biodiversity benefits through payments for carbon sequestration in forests, is constrained by unclear property rights, concerns over the permanence of reductions, and lack of mechanisms for resolving conflicts. Moreover, existing regulatory institutions often do not have ecosystem protection as a clear mandate. For example, independent regulators of privatized water systems and power systems do not necessarily promote resource use efficiency and renewable supply. [R7] The role of the state in setting and enforcing rules continues to be important even in the context of privatization and market-led growth.
- *Development of institutional frameworks that promote a shift from highly sectoral resource management approaches to more integrated approaches* (G, B). In most countries, separate ministries are in charge of various aspects of ecosystems (such as ministries of environment, agriculture, water, and forests) and drivers of change (such as ministries of energy, transportation, development, and trade). Each of these ministries has control over different aspects of ecosystem management. As a result, there is seldom the political will to develop effective ecosystem management strategies, and competition among the ministries can often result in policy choices that are detrimental to ecosystems. Integrated responses intentionally and actively address ecosystem services and human well-being simultaneously, such as integrated coastal zone management, integrated river basin management, and national sustainable development strategies. Although the potential for integrated responses is high, numerous barriers have limited their effectiveness: they are resource-intensive, but the potential benefits can exceed the costs; they require multiple instruments for their implementation; and they require new institutional and governance structures, skills, knowledge, and capacity. Integrated responses at local levels have been successful in using the links between human well-being and ecosystems to design effective interventions, particularly where supportive higher level structures exist.

Economics and Incentives

Economic and financial interventions provide powerful instruments to regulate the use of ecosystem goods and services. [R2] Because many ecosystem services are not traded in markets, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use of the services. Even if people are aware of the services provided by an ecosystem, they are neither compensated for providing these services nor penalized for reducing them. In addition, the people harmed by the degradation of ecosystem services are often not the ones who benefit from the actions leading to

their degradation, and so those costs are not factored into management decisions. A wide range of opportunities exists to influence human behavior to address this challenge in the form of economic and financial instruments. Some of them establish markets; others work through the monetary and financial interests of the targeted social actors; still others affect relative prices.

Market mechanisms can only work if supporting institutions are in place, and thus there is a need to build institutional capacity to enable more widespread use of these mechanisms. [R2, 6, 7, 8, 17] The adoption of economic instruments usually requires a legal framework, and in many cases the choice of a viable and effective economic intervention mechanism is determined by the socioeconomic context. For example, resource taxes can be a powerful instrument to guard against the overexploitation of an ecosystem service, but an effective tax scheme requires well-established and reliable monitoring and tax collection systems. Similarly, subsidies can be effective to introduce and implement certain technologies or management procedures, but they are inappropriate in settings that lack the transparency and accountability needed to prevent corruption. The establishment of market mechanisms also often involves explicit decisions about wealth distribution and resource allocation, when, for example, decisions are made to establish private property rights for resources that were formerly considered common pool resources. For that reason, the inappropriate use of market mechanisms can further exacerbate problems of poverty.

Promising interventions include:

- *Elimination of subsidies that promote excessive use of ecosystem services (and, where possible, transfer of these subsidies to payments for nonmarketed ecosystem services)* (G). Many countries provide significant agricultural production subsidies that lead to greater food production in countries with subsidies than global market conditions warrant; that promote the overuse of water, fertilizers, and pesticides; and that reduce the profitability of agriculture in developing countries. [R7] Subsidies increase land values, adding to landowners' resistance to subsidy reductions. Similar problems are created by fishery subsidies. Although removal of production subsidies would produce net benefits, it would not occur without costs. The farmers and fishers benefiting directly from the subsidies would suffer the most immediate losses, but there would also be indirect effects on ecosystems both locally and globally. In some cases, it may be possible to transfer production subsides to other activities that promote ecosystem stewardship, such as payment for the provision or enhancement of regulatory or supporting services. Compensatory mechanisms may be needed for the poor who are adversely affected by the immediate removal of subsidies. Reduced subsidies within the OECD may lessen pressures on some ecosystems in those countries, but they could lead to more rapid conversion and intensification of land for agriculture in developing countries and would thus need to be accompanied by policies to minimize the adverse impacts on ecosystems there.
- *Greater use of economic instruments and market-based approaches in the management of ecosystem services* (G, B, N). Economic instruments and market mechanisms with the potential to enhance the management of ecosystem services include:
  - *Taxes or user fees for activities with "external" costs* (trade-offs not accounted for in the market). These instruments create incentives that lessen the external costs and provide revenues that can help protect the damaged ecosystem services. Examples include taxes on excessive application of nutrients or ecotourism user fees.
  - *Creation of markets, including through cap-and-trade systems.* Ecosystem services that have been treated as "free" resources, as is often the case for water, tend to be used wastefully. The establishment of markets for the services can both increase the incentives for their conservation and increase the economic efficiency of their allocation if supporting legal and economic institutions are in place. However, as noted earlier, while markets will increase the efficiency of the use of the resource, they can have harmful effects on particular groups of users who may be inequitably affected by the change. The combination of regulated emission caps, coupled with market mechanisms for trading pollution rights, often provides an efficient means of reducing emissions harmful to ecosystems. For example, one of the most rapidly growing markets related to ecosystem services is the carbon market [R13]; in another example, nutrient trading systems may be a low-cost way to reduce water pollution in the United States [R9].
  - *Payment for ecosystem services.* Mechanisms can be established to enable individuals, firms, or the public sector to pay resource owners to provide particular services. For example, in New South Wales, Australia, associations of farmers purchase salinity credits from the State Forests Agency, which in turn contracts with upstream landholders to plant trees, which reduce water tables and store carbon. Similarly, in 1996, Costa Rica established a nationwide system of conservation payments to induce landowners to provide ecosystem services. Under this program, the government brokers contracts between international and domestic "buyers" and local "sellers" of sequestered carbon, biodiversity, watershed services, and scenic beauty. These interventions are found to succeed, typically when a high degree of certainty exists with regard to the accrual of ecosystem services over time.
  - *Mechanisms to enable consumer preferences to be expressed through markets.* Consumer pressure may provide an alternative way to influence producers to adopt more sustainable production practices in the absence of effective government regulation. For example, certification schemes that exist for sustainable fisheries and forest practices provide people with the opportunity to promote sustainability through their consumer choices. Within the forest sector, forest certification

has become widespread in many countries and forest conditions; thus far, however, most certified forests are in temperate regions, managed by large companies that export to northern retailers. [R6] Certification and labeling is also being used at smaller scales. For example, the Salmon Safe initiative in Oregon, United States, certifies and promotes wines and other agricultural products from Oregon farms and vineyards that have adhered to management practices designed to protect water quality and salmon habitat. [R7]

Social and Behavioral Responses

Social and behavioral responses—including population policy, public education, civil society actions, and empowerment of communities, women, and youth—can be instrumental in responding to ecosystem degradation. [R2, 5, 6] These are generally interventions that stakeholders initiate and execute through exercising their procedural or democratic rights in efforts to improve ecosystems and human well-being.

Promising interventions include:

- *Measures to reduce aggregate consumption of unsustainably managed ecosystem services* (G, B, N). The choices about what individuals consume and how much they consume are influenced not just by considerations of price but also by behavioral factors related to culture, ethics, and values. Behavioral changes that could reduce demand for degraded ecosystem services can be encouraged through actions by governments (such as education and public awareness programs or the promotion of demand-side management), industry (such as improved product labeling or commitments to use raw materials from sources certified as sustainable), and civil society (such as public awareness campaigns). Efforts to reduce aggregate consumption, however, must sometimes incorporate measures to increase the access to and consumption of those same ecosystem services by specific groups such as poor people.
- *Communication and education* (G, B, N). Improved communication and education are essential to achieve the objectives of the environmental conventions, the Johannesburg Plan of Implementation, and the sustainable management of natural resources more generally. Both the public and decision-makers can benefit from education concerning ecosystems and human well-being, but education more generally provides tremendous social benefits that can help address many drivers of ecosystem degradation. For example, the Haribon Foundation in the Philippines has used communication, education, and mobilization of networks to motivate fishers and their communities to create marine sanctuaries to allow for fish populations to revive and restore declining catches; over 1,000 reserves have now been established. [R5] Barriers to the effective use of communication and education include a failure to use research and apply modern theories of learning and change. While the importance of communication and education is well recognized, providing the human and financial resources to undertake effective work is a continuing barrier.
- *Empowerment of groups particularly dependent on ecosystem services or affected by their degradation, including women, indigenous people, and young people* (G, B, N). Women, indigenous people, and young people are all important "stakeholders" in the management of ecosystem services but, historically, each group has tended to be marginalized in decision-making processes. For example, despite women's knowledge about the environment and the potential they possess to improve resource management, their participation in decision-making has often been restricted by social and cultural structures. Similarly, the case for protecting young people's ability to take part in decision-making is strong as they will experience the longer-term consequences of decisions made today concerning ecosystem services. Greater involvement of indigenous peoples in decision-making can also enhance environmental management, although the primary justification for it continues to be based on human and cultural rights.

Technological Responses

Given the growing demands for ecosystem services and other increased pressures on ecosystems, the development and diffusion of technologies designed to increase the efficiency of resource use or reduce the impacts of drivers such as climate change and nutrient loading are essential. [R2, 6, 7, 13, 17] Technological change has been essential for meeting growing demands for some ecosystem services, and technology holds considerable promise to help meet future growth in demand. Technologies already exist for reducing nutrient pollution at reasonable costs—including technologies to reduce point source emissions, changes in crop management practices, and precision farming techniques to help control the application of fertilizers to a field, for example—but new policies are needed for these tools to be applied on a sufficient scale to slow and ultimately reverse the increase in nutrient loading (recognizing that this global goal must be achieved even while increasing nutrient applications in relatively poor regions such as sub-Saharan Africa). Many negative impacts on ecosystems and human well-being have resulted from these technological changes, however. The cost of "retrofitting" technologies once their negative consequences become apparent can be extremely high, so careful assessment is needed prior to the introduction of new technologies.

Promising interventions include:

- *Promotion of technologies that increase crop yields without any harmful impacts related to water, nutrient, and pesticide use* (G, B, N). Agricultural expansion will continue to be one of the major drivers of biodiversity loss well into the twenty-first century. Development, assessment, and diffusion of technologies that could increase the production of food per unit area sustainably without harmful trade-offs related to excessive use of water, nutrients, or pesticides would significantly lessen pressure on other ecosystem services.

- *Restoration of ecosystem services* (G, B, N). Ecosystem restoration activities are now common in many countries and include actions to restore almost all types of ecosystems, including wetlands, forests, grasslands, estuaries, coral reefs, and mangroves. Ecosystems with some features of the ones that were present before conversion can often be established and can provide some of the original ecosystem services (such as pollution filtration in wetlands or timber production from forests). The restored systems seldom fully replace the original systems, but they still help meet needs for particular services. Yet the cost of restoration is generally extremely high in relation to the cost of preventing the degradation of the ecosystem. Not all services can be restored, and those that are heavily degraded may require considerable time for restoration.
- *Promotion of technologies to increase energy efficiency and reduce greenhouse gas emissions* (G, B). Significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand, and waste management sectors. Reducing projected emissions will require a portfolio of energy production technologies ranging from fuel switching (coal/oil to gas) and increased power plant efficiency to increased use of renewable energy technologies, complemented by more efficient use of energy in the transportation, buildings, and industry sectors. [R13] It will also involve the development and implementation of supporting institutions and policies to overcome barriers to the diffusion of these technologies into the marketplace, increased public and private-sector funding for research and development, and effective technology transfer.

Knowledge and Cognitive Responses

Effective management of ecosystems is constrained both by a lack of knowledge and information concerning different aspects of ecosystems and by the failure to use adequately the information that does exist in support of management decisions. [R2, 14] Although sufficient information exists to take many actions that could help conserve ecosystems and enhance human well-being, major information gaps exist. In most regions, for example, relatively little is known about the status and economic value of most ecosystem services, and their depletion is rarely tracked in national economic accounts. At the same time, decision-makers do not use all of the relevant information that is available. This is due in part to institutional failures that prevent existing policy-relevant scientific information from being made available to decision-makers. But it is also due to the failure to incorporate other forms of knowledge and information, such as traditional knowledge and practitioners' knowledge, which are of considerable value for ecosystem management.

Promising interventions include:

- *Incorporate both the market and nonmarket values of ecosystems in resource management and investment decisions* (G, B). Most resource management and investment decisions are strongly influenced by considerations of the monetary costs and benefits of alternative policy choices. In the case of ecosystem management, however, this often leads to outcomes that are not in the interest of society, since the nonmarketed values of ecosystems may exceed the marketed values. As a result, many existing resource management policies favor sectors such as agriculture, forestry, and fisheries at the expense of the use of these same ecosystems for water supply, recreation, and cultural services that may be of greater economic value. Decisions can be improved if they include the total economic value of alternative management options and involve deliberative mechanisms that bring to bear noneconomic considerations as well.
- *Use of all relevant forms of knowledge and information in assessments and decision-making, including traditional and practitioners' knowledge* (G, B, N). Effective management of ecosystems typically requires "place-based" knowledge—information about the specific characteristics and history of an ecosystem. Formal scientific information is often one source of such information, but traditional knowledge or practitioners' knowledge held by local resource managers can be of equal or greater value. While that knowledge is used in the decisions taken by those who have it, it is too rarely incorporated into other decision-making processes and is often inappropriately dismissed.
- *Enhance and sustain human and institutional capacity for assessing the consequences of ecosystem change for human well-being and acting on such assessments* (G, B, N). Greater technical capacity is needed for agriculture, forest, and fisheries management. But the capacity that exists for these sectors, as limited as it is in many countries, is still vastly greater than the capacity for effective management of other ecosystem services. Because awareness of the importance of these other services has only recently grown, there is limited experience with assessing ecosystem services fully. Serious limits exist in all countries, but especially in developing countries, in terms of the expertise needed in such areas as monitoring changes in ecosystem services, economic valuation or health assessment of ecosystem changes, and policy analysis related to ecosystem services. Even when such assessment information is available, however, the traditional highly sectoral nature of decision-making and resource management makes the implementation of recommendations difficult. This constraint can also be overcome through increased training of individuals in existing institutions and through institutional reforms to build capacity for more integrated responses.

Appendix R1. Effectiveness of Assessed Responses

A response is considered to be *effective* when its assessment indicates that it has enhanced the particular ecosystem service (or, in the case of biodiversity, its conservation and sustainable use) and contributed to human well-being with-

out significant harm to other ecosystem services or harmful impacts to other groups of people. A response is considered *promising* either if it does not have a long track record to assess but appears likely to succeed or if there are known means of modifying the response so that it can become effective. A response is considered *problematic* if its historical use indicates either that it has not met the goals related to service enhancement (or conservation and sustainable use of biodiversity) or that it has caused significant harm to other ecosystem services. Labeling a response as *effective* does not mean that the historical assessment has not identified problems or harmful trade-offs. Such trade-offs almost always exist, but they are not considered significant enough to negate the effectiveness of the response. Similarly, labeling a response as *problematic* does not mean that there are no promising opportunities to reform the response in a way that can meet its policy goals without undue harm to ecosystem services.

The typology of responses presented here is defined by the nature of intervention, classified as follows: institutional and legal (I), economic and incentives (E), social and behavioral (S), technological (T), and knowledge and cognitive (K). The actors who make decisions to implement a response are governments at different levels, such as international (GI) (mainly through multilateral agreements or international conventions), national (GN), and local (GL); the business/industry sector (B); and civil society, which includes nongovernmental organizations (NGO), community-based and indigenous peoples' organizations (C), and research institutions (R). The actors are not necessarily equally important.

The table includes responses assessed for a range of ecosystem services—food, fresh water, wood, nutrient management, flood and storm control, disease regulation, and cultural services. It also assesses responses for biodiversity conservation, integrated responses, and responses addressing one specific driver: climate change.

Response	Effectiveness: Effective	Effectiveness: Promising	Effectiveness: Problematic	Notes	Type of Response	Required Actors
Biodiversity Conservation and Sustainable Use						
Protected areas	■	■		PAs are extremely important in biodiversity and ecosystem conservation programs, especially in sensitive environments that contain valuable biodiversity components. At global and regional scales, existing PAs are essential but not sufficient to conserve the full range of biodiversity. PAs need to be better located, designed, and managed to ensure representativeness and to deal with the impacts of human settlement within PAs, illegal harvesting, unsustainable tourism, invasive species, and climate change. They also need a landscape approach that includes protection outside of PAs. [R5]	I	GI GN GL NGO C R
Helping local people capture biodiversity benefits		■	■	Providing incentives for biodiversity conservation in the form of benefits for local people (e.g., through products from single species or from ecotourism) has proved to be very difficult. Programs have been more successful when local communities have been in a position to make management decisions consistent with overall biodiversity conservation. "Win-win" opportunities for biodiversity conservation and benefits for local communities exist, but local communities can often achieve greater benefits from actions that lead to biodiversity loss. [R5]	E	GN GL B NGO C
Promoting better management of wild species as a conservation tool, including ex situ conservation	■			More effective management of individual species should enhance biodiversity conservation and sustainable use. "Habitat-based" approaches are critical, but they cannot replace "species-based" approaches. Zoos, botanical gardens, and other ex situ programs build support for conservation, support valuable research, and provide cultural benefits of biodiversity. [R5]	T S	GN C NGO R
Integrating biodiversity into regional planning	■			Integrated regional planning can provide a balance among land uses that promotes effective trade-offs among biodiversity, ecosystem services, and other needs of society. Great uncertainty remains as to what components of biodiversity persist under different management regimes, limiting the current effectiveness of this approach. [R5]	I	GN GL NGO
Encouraging private sector involvement in biodiversity conservation		■		Many companies are preparing their own biodiversity action plans, managing their landholdings in ways that are more compatible with biodiversity conservation, supporting certification schemes that promote more sustainable use, and accepting their responsibility for addressing biodiversity issues. The business case that has been made for larger companies needs to be extended to other companies as well. [R5]	I	GN B NGO R
Including biodiversity issues in agriculture, forestry, and fisheries		■		More diverse production systems can be as effective as low-diversity systems, or even more effective. Strategies based on more intensive production rather than on the expansion of the area allow for better conservation. [R5]	T	GN B

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Designing governance approaches to support biodiversity				Decentralization of biodiversity management in many parts of the world has had variable results. The key to success is strong institutions at all levels, with secure tenure and authority at local levels essential to providing incentives for sustainable management. [R5]	I	GI GN GL R
Promoting international cooperation through multilateral environmental agreements				MEAs should serve as an effective means for international cooperation in the areas of biodiversity conservation and sustainable use. They cover the most pressing drivers and issues related to biodiversity loss. Better coordination between conventions would increase their usefulness. [R5,15]	I	GI GN
Environmental education and communication				Environmental education and communication programs have both informed and changed preferences for biodiversity conservation and have improved implementation of biodiversity responses. Providing the human and financial resources to undertake effective work in this area is a continuing challenge. [R5]	S	GN GL NGO C
Food						
Globalization, trade, and domestic and international policies on food				Government policies related to food production (price supports and various types of payments, or taxes) can have adverse economic, social, and environmental effects. [R6]	E	GI GN B
Knowledge and education				Further research can make food production socially, economically, and environmentally sustainable. Public education should enable consumers to make informed choices about nutritious, safe, and affordable food. [R6]	S K	GN GL NGO C
Technological responses, including biotechnology, precision agriculture, and organic farming				New agricultural sciences and effective natural resource management could support a new agricultural revolution to meet worldwide food needs. This would help environmental, economic, and social sustainability. [R6]	T	GN B R
Water management				Emerging water pricing schemes and water markets indicate that water pricing can be a means for efficient allocation and responsible use. [R6]	E	GN GL B NGO
Fisheries management				Strict regulation of marine fisheries is needed, both regarding the establishment and implementation of quotas and steps to address unreported and unregulated harvest. Individual transferable quotas also show promise for cold water, single-species fisheries, but they are unlikely to be useful in multispecies tropical fisheries. Given the potential detrimental environmental impacts of aquaculture, appropriate regulatory mechanisms need to supplement existing policies. [R6]	I E	GN GL B NGO

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Livestock management				Livestock policies need to be reoriented in view of problems concerning overgrazing and dryland degradation, rangeland fragmentation and loss of wildlife habitat, dust formation, bush encroachment, deforestation, nutrient overload through disposal of manure, and greenhouse gas emissions. Policies also need to focus on human health issues related to diseases such as bird flu and BSE. [R6]	T	GN B
Recognition of gender issues				Response policies need to be gender-sensitive and designed to empower women and ensure access to and control of resources necessary for food security. This needs to be based on a systematic analysis of gender dynamics and explicit consideration of relationships between gender and food and water security. [R6]	S	GN NGO C
Fresh Water						
Determining ecosystem water requirements				In order to balance competing demands, it is critical that society explicitly agrees on ecosystem water requirements (environmental flows). [R7]	I T	GN GL NGO R
Rights to freshwater services and responsibilities for their provision				Both public and private ownership systems of fresh water, and of the land resources associated with its provision, have largely failed to create incentives for provision of water services. As a result, upland communities have generally been excluded from access to benefits, particularly when they lack tenure security, and have resisted regulations regarded as unfair. Effective property rights systems with clear and transparent rules can increase stakeholders' confidence that they will have access to the benefits of freshwater services and, therefore, willingness to pay for them. [R7]	I	GN B C
Increasing the effectiveness of public participation in decision-making				Degradation of freshwater and other ecosystem services has a disproportionate impact on those excluded from participation in decision-making. Key steps for improving participatory processes are to increase the transparency of information, improve the representation of marginalized stakeholders, engage them in the establishment of policy objectives and priorities for the allocation of freshwater services, and create space for deliberation and learning that accommodates multiple perspectives. [R7]	I	GN GL NGO C R
River basin organizations				RBOs can play an important role in facilitating cooperation and reducing transaction costs of large-scale responses. RBOs are constrained or enabled primarily by the degree of stakeholder participation, their agreement on objectives and management plans, and their cooperation on implementation. [R7]	I	GI GN NGO

Response	Effectiveness: Effective	Effectiveness: Promising	Effectiveness: Problematic	Notes	Type of Response	Required Actors
Regulatory responses				Regulatory approaches based on market-based incentives (e.g., damages for exceeding pollution standards) are suitable for point-source pollutants. Regulatory approaches that simply outlaw particular types of behavior can be unwieldy and burdensome, and may fail to provide incentives for protecting freshwater services. [R7]	I	GN GL
Water markets				Economic incentives can potentially unlock significant supply- and demand-side efficiencies while providing cost-effective reallocation between old (largely irrigation) and new (largely municipal and instream) uses. [R7]	E	GI GN B
Payments for watershed services				Payments for ecosystem services provided by watersheds have narrowly focused on the role of forests in the hydrological regime. They should be based on the entire flow regime, including consideration of the relative values of other land cover and land uses, such as wetlands, riparian areas, steep slopes, roads, and management practices. Key challenges for payment schemes are capacity-building for place-based monitoring and assessment, identifying services in the context of the entire flow regime, considering trade-offs and conflicts among multiple uses, and making uncertainty explicit. [R7]	E	GN B C
Partnerships and financing				There is a clear mismatch between the high social value of freshwater services and the resources allocated to manage water. Insufficient funding for water infrastructure is one manifestation of this. Focusing only on large-scale privatization to improve efficiency and cost-recovery has proven a double-edged strategy—price hikes or control over resources have created controversy and, in some cases, failure and withdrawal. Development of water infrastructure and technologies must observe best practices to avoid problems and inequities. The re-examination and retrofitting/refurbishment of existing infrastructure is the best option in the short and medium term. [R7]	I E	GI GN B NGO C
Large dams				The impact of large dams on freshwater ecosystems is widely recognized as being more negative than positive. In addition, the benefits of their construction have rarely been shared equitably—the poor and vulnerable and future generations often fail to receive the social and economic benefits from dams. Pre-construction studies are typically overly optimistic about the benefits of projects and underestimate costs. [R7]	T	GN
Wetland restoration				Although wetland restoration is a promising management approach, there are significant challenges in determining what set of management interventions will produce a desired combination of wetland structure and function. It is unlikely that created wetlands can structurally and functionally replace natural wetlands. [R7]	T	GN GL NGO B

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Wood, Fuelwood, and Non-wood Forest Products						
International forest policy processes and development assistance				International forest policy processes have made some gains within the forest sector. Attention should be paid to integration of agreed forest management practices in financial institutions, trade rules, global environment programs, and global security decision-making. [R8]	I	GI GN B
Trade liberalization				Forest product trade tends to concentrate decision-making power on (and benefits from) forest management, rather than spreading it to include poorer and less powerful players. It "magnifies" the effect of governance, making good governance better and bad governance worse. Trade liberalization can stimulate a "virtuous cycle" if the regulatory framework is robust and externalities are addressed. [R8]	E	GI GN
National forest governance initiatives and national forest programs				Forest governance initiatives and country-led national forest programs show promise for integrating ecosystem health and human well-being where they are negotiated by stakeholders and strategically focused. [R8]	I	GN GL
Direct management of forests by indigenous peoples				Indigenous control of traditional homelands is often presented as having environmental benefits, although the main justification continues to be based on human and cultural rights. Little systematic data exist, but preliminary findings on vegetation cover and forest fragmentation from the Brazilian Amazon suggest that an indigenous-control area can be at least as effective as a strict-use protected area. [R8]	I	GL C
Collaborative forest management and local movements for access and use of forest products				Government–community collaborative forest management can be highly beneficial but has had mixed results. Programs have generated improved resource management and access of the rural poor to forest resources, but have fallen short in their potential to benefit the poor. Local responses to problems of access and use of forest products have proliferated in recent years. They are collectively more significant than efforts led by governments or international processes but require their support to spread. [R8]	I	GN GL B NGO C
Small-scale private and public-private ownership and management of forests				Small-scale private ownership of forests can deliver more local economic benefits and better forest management than ownership by larger corporate bodies where information, tenure, and capacity are strong. [R8]	I	GL B C
Company–community forestry partnerships				Company–community partnerships can be better than solely corporate forestry, or solely community or small-scale farm forestry, in delivering benefits to the partners and the public at large. [R8]	I	GL B C

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Public and consumer action				Public and consumer action has resulted in important forest and trade policy initiatives and improved practices in large forest corporations. This has had an impact in "timber-consuming countries" and in international institutions. The operating standards of some large corporations and institutions, as well as of those whose non-forest activities have an impact on forests, have been improved. [R8]	S	NGO B C
Third-party voluntary forest certification				Forest certification has become widespread; however, most certified forests are in industrial countries, managed by large companies and exporting to Northern retailers. The early proponents of certification hoped it would be an effective response to tropical deforestation. [R8]	I E	B
Wood technology and biotechnology				Wood technology responses have focused on industrial plantation species with properties suited for manufactured products. [R8]	T	GN R B
Commercialization of non-wood forest products				Commercialization of NWFP has had modest impacts on local livelihoods and has not always created incentives for conservation. An increased value of NWFPs is not always an incentive for conservation and can have the opposite effect. Incentives for sustainable management of NWFPs should be reconsidered, including exploration of joint production of timber and NWFP. [R8]	E	NGO B R
Natural forest management in the tropics				To be economic, sustainable natural forest management in the tropics must focus on a range of forest goods and services, not just timber. The "best practices" of global corporations should be assessed, exploring at the same time "what works" in traditional forest management and the work of local (small) enterprises. Considerable interest has developed in the application of reduced impact logging, especially in tropical forests, which lowers environmental impacts and can also be more efficient and cost effective. [R8]	T	GI GN GL B NGO C
Forest plantation management				Farm woodlots and large-scale plantations are increasingly being established in response to growing wood demand and declining natural forest areas. Without adequate planning and management, forest plantations can be established in the wrong sites, with the wrong species and provenances. In degraded lands, afforestation may deliver economic, environmental, and social benefits to communities and help in reducing poverty and enhancing food security. [R8]	T	GN GL B NGO R
Fuelwood management				Fuelwood remains one of the main products of the forest sector in developing countries. If technology development continues, industrial-scale forest product fuels could become a major sustainable energy source. [R8]	T	GL B C

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Afforestation and reforestation for carbon management				Although many early initiatives were based on forest conservation or management, afforestation activities now predominate, perhaps reflecting the international decisions in 2001 to allow only afforestation and reforestation activities into the Clean Development Mechanism for the first commitment period. [R8]	T E	GI GN B
Nutrient Cycling						
Regulations				Mandatory policies, including regulatory control and tax or fee systems, place the costs and burden of pollution control on the polluter. Technology-based standards are easy to implement but may discourage innovation and are generally not seen as cost-effective. [R9]	I	GI GN
Market-based instruments				Market-based instruments, such as financial incentives, subsidies, and taxes, hold potential for better nutrient management, but may not be relevant in all countries and circumstances. Relatively little is known empirically about the impact of these instruments on technological change. [R9]	E	GN B R
Hybrid approaches				Combinations of regulatory, incentive, and market-based mechanisms are possible for both national and watershed-based approaches and may be the most cost-effective and politically acceptable. [R9]	I E	GI GN GL NGO C R
Flood and Storm Regulation						
Physical structures				Historically, emphasis was on physical structures/measures over natural environment and social institutions. This choice often creates a false sense of security, encouraging people to accept high risks. Evidence indicates that more emphasis needs to be given to the natural environment and nonstructural measures. [R11]	T	GN B
Use of natural environment				Flood and storm impacts can be lessened through maintenance and management of vegetation and through natural or human-made geomorphological features (natural river channels, dune systems, terrace farming). [R11]	T	GN GL NGO C
Information, institutions, and education				These approaches, which emphasize disaster preparedness, disaster management, flood and storm forecasting, early warning, and evacuation, are vital for reducing losses. [R11]	S I	GN GL B C
Financial services				These responses emphasize insurance, disaster relief, and aid. Both social programs and private insurance are important coping mechanisms for flood disaster recovery. They can, however, inadvertently contribute to community vulnerability by encouraging development within floodplains or by creating cultures of entitlement. [R11]	E	GN B

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
Land use planning		■		Land use planning is a process of determining the most desirable type of land use. It can help to mitigate disasters and reduce risks by avoiding development in hazard prone areas. [R11]	I	GN
Disease Regulation						
Integrated vector management		■		Reducing the transmission of infectious diseases often has effects on other ecosystem services. IVM enables a coordinated response to health and the environment. It uses targeted interventions to remove or control vector breeding sites, disrupt vector lifecycles, and minimize vector-human contact, while minimizing effects on other ecosystem services. IVM is most effective when integrated with socioeconomic development. [R12]	I	GN NGO
Environmental management/ modification to reduce vector and reservoir host abundance		■		Environmental management interventions can be highly cost-effective and entail very low environmental impacts. [R12]	I	GN B C R
Biological control/natural predators	■			Biological interventions can be highly cost-effective and entail very low environmental impacts. Biological control may be effective if breeding sites are well known and limited in number, but less feasible where these are numerous. [R12]	T	GN B R
Chemical control			■	Insecticides remain an important tool and their selective use is likely to continue within IVM. However, there are concerns regarding the impacts of insecticides, especially persistent organic pollutants, on the environment and on human populations, particularly insecticide sprayers. [R12]	T	GN B R
Human settlement patterns	■			The most basic management of human-vector contact is through improvements in the placement and construction of housing. [R12]	T	GN NGO C
Health awareness and behavior	■			Social and behavioral responses can help control vector-borne disease while also improving other ecosystem services. [R12]	S	C
Genetic modification of vector species to limit disease transmission			■	New "cutting-edge" interventions, such as transgenic techniques, could be available within the next 5–10 years. However, consensus is lacking in the scientific community on the technical feasibility and public acceptability of such an approach. [R12]	T	GN B NGO R
Cultural Services						
Awareness of the global environment and linking local and global institutions	■			Awareness of the planet working as a system has led to an integrated approach to ecosystems. This process has emphasized the "human environment" concept and the discussion of environmental problems at a global scale. Local organizations also take advantage of emerging global institutions and conventions to bring their case to wider political arenas. [R14]	S I	GI GN GL

Response	Effectiveness			Notes	Type of Response	Required Actors
	Effective	Promising	Problematic			
From restoring landscapes to valuing cultural landscapes				Landscapes are subject to and influenced by cultural perceptions and political and economic interests. This influences decisions on landscape conservation. [R14]	S K	GL NGO C
Recognizing sacred areas				While linking sacred areas and conservation is not new, there has been an increase in translating "the sacred" into legislation or legal institutions granting land rights. This requires extensive knowledge about the link among the sacred, nature, and society in a specific locale. [R14]	S	GL NGO C
International agreements and conservation of biological and agropastoral diversity				Increased exploitation and awareness concerning the disappearance of local resources and knowledge has highlighted the need to protect local and indigenous knowledge. Some countries have adopted specific laws, policies, and administrative arrangements emphasizing the concept of prior informed consent of knowledge-holders. [R14]	I	GI GN
Integrating local and indigenous knowledge				Local and indigenous knowledge evolves in specific contexts and good care should be taken to not de-contextualize it. Conventional "best-practices" methods focusing on content may not be appropriate to deal with local/indigenous knowledge. [R14]	K I	GN B NGO
Compensating for knowledge				Compensation for the use of local and indigenous knowledge by third parties is an important, yet complicated response. The popular idea that local and indigenous knowledge can be promoted by strengthening "traditional" authorities may not be valid in many cases. [R14]	E K	GN B C
Property right changes				Communities benefit from control over natural resources but traditional leadership may not always be the solution. Local government institutions that are democratically elected and have real authority over resources in some cases may be a better option. There is a tendency to shift responsibilities back and forth between "traditional" authorities and local government bodies, without giving any of them real decision-making powers. [R14]	I	GN GL C
Certification programs				Certification programs are a promising response, but many communities do not have access to these programs or are not aware of their existence. In addition, the financial costs involved reduce the chances for local communities to participate independently. [R14]	I S	GI GN B
Fair trade				Fair trade is a movement initiated to help disadvantaged or politically marginalized communities by paying better prices and providing better trading conditions, along with raising consumers' awareness of their potential role as buyers. Fair trade overlaps in some cases with initiatives focusing on the environmental performance of trade. [R14]	E S	GI GN GL NGO C

Response	Effectiveness: Effective	Effectiveness: Promising	Effectiveness: Problematic	Notes	Type of Response	Required Actors
Ecotourism and cultural tourism		■		Ecotourism can provide economic alternatives to converting ecosystems; however, it can generate conflicts in resource use and the aesthetics of certain ecosystems. Different ecosystems are subjected to different types and scales of impact from tourism infrastructure. Furthermore, some ecosystems are easier to market to tourists than others. The market value of ecosystems may vary according to public perceptions of nature. Freezing of landscapes, conversion of landscapes, dispossession, and removing of human influences may result, depending on views of what ecotourism should represent. Yet when conservation receives no budgetary subsidy, tourism can provide revenues for conservation. [R14]	E	GL B C
Integrated Responses						
International environmental governance		■		Environmental policy integration at the international level is almost exclusively dependent on governments' commitment to binding compromises on given issues. Major challenges include reform of the international environmental governance structure and coherence among international trade and environment mechanisms. [R15]	I E K T B	GI GN
National action plans and strategies aiming to integrate environmental issues into national policies		■		Examples include national conservation strategies, national environmental action plans, and national strategies for sustainable development. Success depends on enabling conditions such as ownership by governments and civil society, broad participation, both across sectors within the government and with the private sector, and at the sub-national and local scales. National integrated responses may be a good starting point for cross-departmental linkages in governments. [R15]	I E K T	GN GL B NGO C
Sub-national and local integrated approaches	■	■		Many integrated responses are implemented at the sub-national level; examples include sustainable forest management, integrated coastal zone management, integrated conservation and development programs, and integrated river basin management. Results so far have been varied, and a major constraint experienced by sub-national and multiscale responses is the lack of implementation capacity. [R15]	I E K T	GN GL NGO C
Waste Management						
Technologies for waste reduction, re-use, recovery, and disposal	■			These practices have enhanced ecosystem services, improved aesthetic conditions, restored habitats for human use and for biodiversity, increased public health and well-being, created jobs, and reduced poverty. [R10]	T	GN GL B C
Compliance with waste management laws and regulations		■		Communities and industries are willing to comply with laws and regulations if there is clear understanding of the benefits and if all stakeholders are involved in the formulation of such laws. [R10]	L	GN GL

Response	Effectiveness: Effective	Effectiveness: Promising	Effectiveness: Problematic	Notes	Type of Response	Required Actors
Environmental awareness and education				Environmental awareness and education have succeeded in allowing consumers and resource users to make informed choices for minimizing waste. Employers have introduced programs to encourage communities to reduce waste. [R10]	S	GL C B
Indicators and monitoring				Industries and governments need to select indicators and standardize methods to monitor the sources, types, and amounts of all wastes produced. The practice of transparent, participatory, and accountable decision-making for ecosystem sustainability and human well-being is lacking in many countries. [R10]	S	GN B NGO
Climate Change						
U.N. Framework Convention on Climate Change and Kyoto Protocol				The ultimate goal of the UNFCCC is stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Kyoto Protocol contains binding limits on greenhouse gas emissions on industrialized countries that agreed to reduce their emissions by an average of about 5% between 2008 and 2012 relative to the levels emitted in 1990. [R13]	I	GI GN
Reductions in net greenhouse gas emissions				Significant reductions in net greenhouse gas emissions are technically feasible, in many cases at little or no cost to society. [R13]	T	GN B C
Land use and land cover change				Afforestation; reforestation; improved forest, cropland, and rangeland management; and agroforestry provide opportunities to increase carbon uptake, and slowing deforestation reduces emissions. [R13]	T	GN GL B NGO C
Market mechanisms and incentives				The Kyoto Protocol mechanisms, in combination with national and regional ones, can reduce the costs of mitigation for developed countries. In addition, countries can reduce net costs of emissions abatement by taxing emissions (or auctioning permits) and using the revenues to cut distortion taxes on labor and capital. In the near term, project-based trading can facilitate the transfer of climate-friendly technologies to developing countries. [R13]	E	GI GN B
Adaptation				Some climate change is inevitable and ecosystems and human societies will need to adapt to new conditions. Human populations will face the risk of damage from climate change, some of which may be countered with current coping systems; others may need radically new behaviors. Climate change needs to be factored into current development plans. [R13]	I	GN GL NGO C R

Chapter 5

Multiscale Assessments: Integrated Assessments at Multiple Scales

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CONTENTS

1. What Are the MA Sub-global Assessments?

The MA, which focused on ecosystem change and the impacts of such change on human well-being, included a set of sub-global assessments at multiple spatial scales, in addition to the global assessment. This was one of the innovations of the MA compared to other international assessments, which usually focus on global or regional scales alone. The global and sub-global assessments analyzed ecosystem services and human well-being from different perspectives and with different stakeholders involved. The MA sub-global assessments were led by institutions and individuals in those countries where the sub-global assessments were carried out.

The MA sub-global assessments were conceived as integrated assessments to analyze the relationship between direct and indirect drivers of ecosystem change, their impact on ecosystem services, and the consequences for human well-being. They were also designed to compare different spatial scales, involve a diverse set of stakeholders, and use different knowledge systems as part of the assessment process. This volume presents an overview of the main outcomes and conclusions from this process, with reflections on the lessons learned.

The MA design for sub-global assessments was intended to develop and test methodologies for multiscale assessments, meet the information needs of decision-makers at every scale, and build capacity to undertake such assessments. The initial approach taken was to develop sets of nested, multiscale assessments in selected regions of the world, complemented by a "cross-cutting" assessment of similar ecosystems in different locations and an "outlier" assessment in an ecosystem or region not otherwise represented. As the process developed, however, a bottom-up approach was adopted, backed by an open call for proposals and a set of selection criteria related to assessment design and stakeholder engagement. Many sub-global assessments were established where demand and interest in such assessments arose. This resulted in a globally diverse set of assessments that were driven by user demand but did not represent a comprehensive selection or uniform sampling of ecosystems and locations around the world. [SG2]

The MA process included a total of 34 sub-global assessments from around the world. These assessments analyzed the importance of ecosystem services for human well-being at local, national, and regional scales. The areas covered in these assessments ranged from small villages in India, to cities like Kristianstad (Sweden) and São Paulo (Brazil), to whole countries like Portugal, and large regions like southern Africa. (See Figure SG1.) A short overview of each of the assessments involved is presented in Appendix B of this volume, and additional information is available on the MA website.

The MA design called for sub-global assessments covering multiple nested scales. For example, the Southern Africa sub-global assessment (SAfMA) included assessments of the entire region of Africa south of the equator, of the Gariep and Zambezi river basins in that region, and of local communities within those basins. (See Figure SG2.) This nested design was part of the overall design of the MA to analyze the importance of scale on ecosystem services and human well-being and to study cross-scale interactions. However, most sub-global assessments were conducted at a single spatial scale, with some multiscale analysis. [SG2, 4]

The sub-global assessments included a diversity of ecosystems. Examples include drylands in Chile and western China; tropical rainforests in the Amazon, Central Africa, and Southeast Asia; coastal and marine ecosystems in the Caribbean Sea and Papua New Guinea, and urban ecosystems in Sweden and Brazil, among others. Many assessments analyzed several ecosystems within a single study area. The majority of assessments (26 out of 34) included forests, inland water, or cultivated systems, which were the systems most commonly assessed. Island, coastal, and marine systems were not as widely represented (11 out of 34 assessed at least one of those systems), nor were urban systems (5 out of 34). Polar systems were not covered. [SG2]

The sub-global assessments involved a diversity of stakeholders in their processes, including local, regional and national governments, nongovernmental organizations, local communities, research and academic institutions, and, to a lesser extent, the private sector and international organizations. The institutions leading the assessments were different across assessments, but they were often academic or research institutions. Including a diversity of stakeholders is considered essential for effective assessments, as it enhances stakeholder ownership of the outcomes. [SG6]

2. What Did We Learn?

Ecosystem services are important for many dimensions of human well-being, some of which are best observed at sub-global scales.

People everywhere in the world rely on ecosystems for their well-being. The sub-global assessments provided many examples, at all scales, from local to global; in all parts of the world, from the least to the most developed; and for all peoples, from the poorest to the wealthiest, from the most rural to the most urban. Some ecosystems provide direct benefits for people: forest dwellers in Papua New Guinea harvest foods from the rainforest, fishermen in Trinidad harvest fish from the ocean, local populations in Viet Nam use plant species for medicinal purposes, and villagers in Zambia rely on wood for a variety of needs. (See Box SG1.) In other cases, the benefits from ecosystems come from regulating services essential to human well-being. Evidence suggests that the people of São Paulo, Brazil, benefit from the surrounding belt of forest that regulates both the temperature and the quality of the air in the city. The wetlands in Kristianstad, Sweden, have an important function in buffering the local population from annual flooding events. Ecosystems can also provide important cultural and spiritual services for local communities in both rural and urban settings. [SG3]

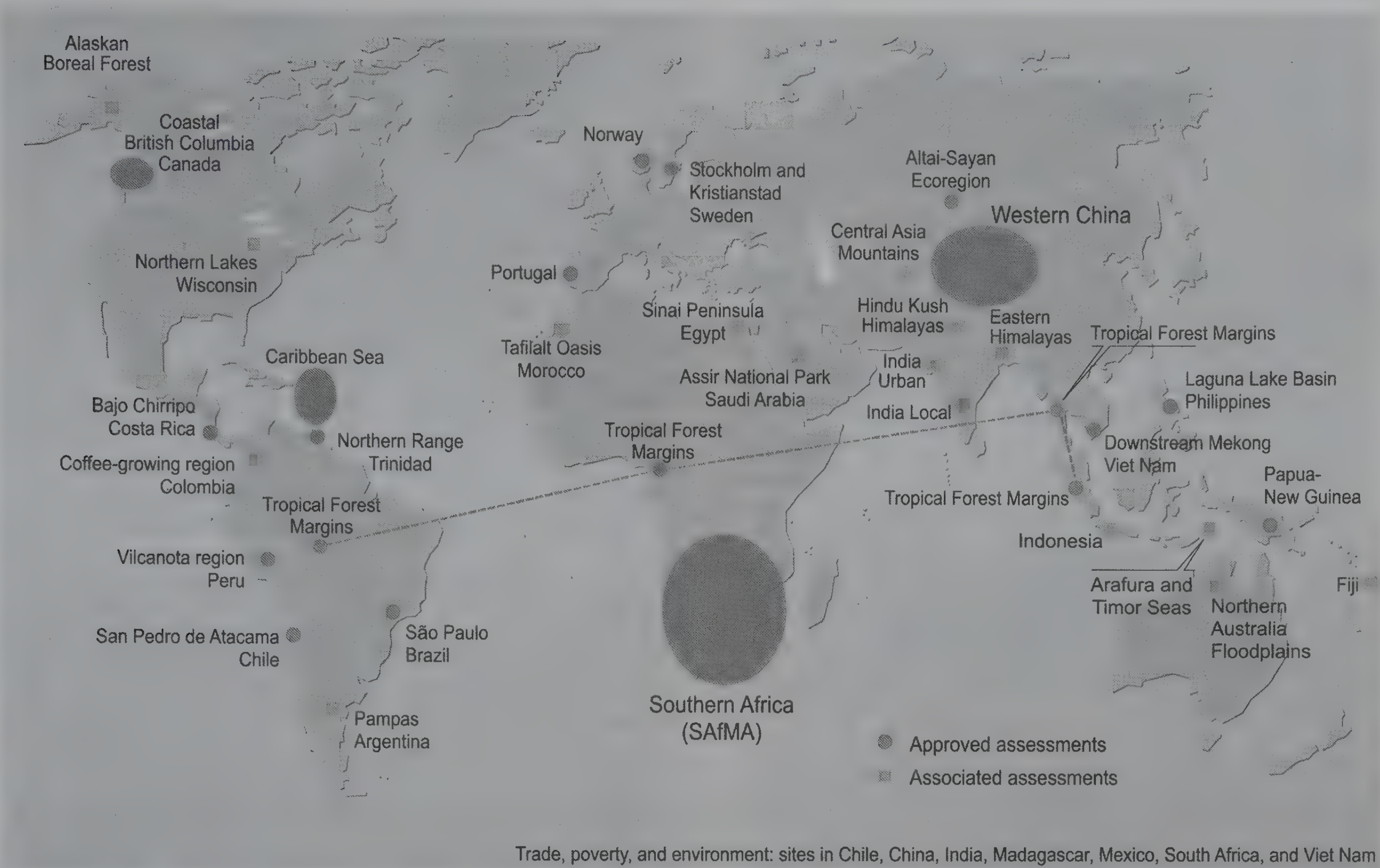

Figure SG1. Map Showing the Global Distribution of Sub-global Assessments that were Part of the Millennium Ecosystem Assessment (MA). The approved assessments were formally approved by the MA Board and followed all the guidelines of the MA, including an analysis of all components of the conceptual framework. Associated assessments used the conceptual framework, but did not necessarily analyze all components.

Spiritual and cultural services are regarded as important ecosystem services at local scales, for wealthy as well as for poor communities and in both rural and urban settings. Several assessments conducted with and by local communities highlighted the importance of spiritual and cultural services. For example, local villages in India preserve selected sacred groves of forest for spiritual reasons. Urban parks provide important cultural and recreational services in cities around the world, such as in Stockholm, where the principal urban park receives some 15 million visits every year. (See Box SG2.) [SG3]

There are clear trade-offs among ecosystem services; the nature of these trade-offs are context-specific and differ across assessments. The analyses performed by the sub-global assessments, in agreement with the global results, generally show an increase in provisioning services over time, at the expense of regulating services, supporting services, and biodiversity. For example, deforestation caused by increased local demand for wood resulted in an increase in human disease in India (see Box SG3), and mining and tourism activities in San Pedro de Atacama in Chile have had an impact on the availability and access to water by local populations. [SG3]

The relationship between ecosystem services and human well-being can take on several different forms. The sub-global assessments found a wide range of relationships between ecosystem services and human well-being. Often, rising incomes are initially accompanied by declines in some ecosystem services. In the assessment of the downstream Mekong wetlands in Viet Nam, for example, economic growth from agricultural expansion has improved human well-being, but at the expense of soil quality. Once a sufficient level of wealth is achieved, societal priorities may emphasize the quality of the environment and the services it delivers. This was most obvious in the assessment of the Stockholm Urban Park, Sweden, where stakeholders are minimizing the impacts of urban sprawl. In some cases, there is no evidence for such a turnaround, and some services may decline continuously with increasing wealth. For instance, water as a provisioning service continues to be degraded in the wealthy, urban area of Gauteng in South Africa. In yet other cases, a particular service may possibly improve continuously in tandem with increasing wealth, which would be the case in Viet Nam if increasing agricultural production were managed sustainably. The sub-global assessments did not equate human well-being with wealth, but wealth was an important and frequently measured component of well-being. [SG3]

In places where there are no social safety nets, diminished human well-being tends to increase im-

Figure SG2. The Multiscale Assessment in Southern Africa and its Nested Design. The assessment consisted of a regional component which included all countries in Africa south of the equator, basin assessments of the Gariep and Zambezi rivers, and five local assessments within those basins.

BOX SG1

Fuelwood, Water, and Health in Zambia

In the Kafue basin of Zambia, wood constitutes 96% of household energy consumption. Shortage of wood fuel occurs in areas with high population density without access to alternative and affordable energy sources. In those provinces of Zambia where population densities exceed the national average of 13.7 persons per square kilometer, the demand for wood has already surpassed local supply. In such areas, people are vulnerable to illness and malnutrition because it is too expensive to heat homes, not possible to cook food, and consumption of unboiled water facilitates the spread of waterborne diseases such as cholera. Women and children in rural poor communities are the most affected by wood fuel scarcity. They must walk long distances searching for firewood, and therefore have less time for tending crops, cooking meals, or attending school.

BOX SG2

Recreation in Urban Parks in Sweden

The National Urban Park in Stockholm, Sweden, receives 15 million visitors per year, most of whom visit the park for recreational purposes. More than 90% of the urban population in Stockholm visits the city's green area at least once a year, and about half of those visit at least weekly. Recreation in this park system promotes physical exercise and mental well-being. The green area allows humans to come into contact with nature and provides a resource for natural science teaching.

BOX SG3

Deforestation and Human Disease in India

In Koyyur village, India, deforestation has resulted in increased human disease. Growing demand for wood and other forest products caused an increase in canopy gaps in the rainforest, which allowed more sunlight to reach the forest floor. The resulting increased growth of grasses and other fodder species attracted cattle from the villages. These cattle carry ticks that transmit a monkey fever (Kyasanur forest disease) that affects people, resulting in an increase in the disease in humans.

mediate dependence on ecosystem services. The resultant additional pressure can damage the capacity of those local ecosystems to deliver services, and this capacity can decline to such a degree that the probability of disaster or conflict increases. For example, rural communities in the former tribal "homelands" in South Africa had no rights of permanent residence outside those areas, and they had few economic opportunities within them. As a result, they depended on the ecosystem resources that the areas offered, and in many cases overexploited them. In this type of relationship between poverty and the environment, particularly when property rights are not clearly defined and resource management institutions are weak, poor people can sink further into poverty as they are driven to participate in unsustainable resource use regimes. [SG11]

Inequities in the distribution of the costs and benefits of ecosystem change are often displaced to other places, groups, or future generations. For example, the economic clout of cities enables many urban populations to draw on resources from distant ecosystems, and this trend is expected to continue with increasing urbanization; the Gariep basin assessment, for example, showed that the population of the urban area of Gauteng province in South Africa consumes nearly 30 times more wheat than is produced in the province itself. The increase in international trade is also generating additional pressures on ecosystem services around the world, illustrated in the cases of the mining industries in Chile (see Box SG4) and Papua New Guinea. In some cases, the costs of transforming ecosystems are simply deferred to future generations. An example reported widely across sub-global assessments in different parts of the world

BOX SG4

Mining, Water, and Human Well-being in Chile

San Pedro de Atacama, Chile, is located within the driest desert in the world. Surface water is limited. The present major concern is over groundwater usage and the extent to which its exploitation is sustainable. The economic activities in this area include mining, agriculture, and tourism, all of which depend on the quantity and quality of available water. The Salar de Atacama (a salty wetland) holds over 40% of world lithium reserves; mining provides 12% of employment in the municipality; and two-thirds of the regional GDP. Mining is the most important user of groundwater (almost 100% of groundwater rights). Tourism is the second largest source of employment and income, and needs fresh water for its facilities (potable water amounts to 16% of surface water rights). Local communities rely on water for subsistence agriculture and livestock raising (accounting for 83% of surface water rights). Most subsistence farmers do not have enough resources to buy water rights, when bidding against other users. Hence the shortage of water generates major conflicts over access and ownership rights among the competing users.

was tropical deforestation, which caters to current needs but leads to a reduced capacity to supply services in the future.

The condition and trends of many ecosystem services, observed at multiple scales, are declining in many locations worldwide.

The sub-global assessments showed that ecosystem services are declining in many regions around the world. Despite some gains in the provisioning of food, water, and wood, the ecological capacity of the systems to continue to provide services is at risk in several locations. Problems with provisioning services include deterioration of water quality, deterioration of agricultural soils, and insufficient supply to meet demand. Some of the threats affecting regulating services are loss of forest cover, rangeland degradation by overgrazing (particularly in drylands), loss of wetlands to urban development and agriculture, and change in fire frequency. Problems with cultural services include loss of cultural identity and negative impacts from tourism. Biodiversity is decreasing due to the loss and fragmentation of natural habitats and the reduction of species population sizes, particularly of large bodied species, species occupying high trophic levels, and species that are harvested by humans. [SG8]

Conclusions on conditions and trends may differ between global and sub-global analyses. Although there was overall congruence in the results from global and sub-global assessments for services like water and biodiversity, there were instances where local assessments showed the condition as either better or worse than expected from the global assessment. For example, the condition of water resources, as assessed in the sub-global assessments, was significantly worse than might have been expected from the global assessment in places like São Paulo (Brazil) and the Laguna Lake Basin (Philippines). (See Figure SG3.) On the other hand, biodiversity condition in the Gorongosa-Marromeu component of the southern Africa assessment (SAfMA) was assessed to be better than the global assessment suggested. There were more instances of results differing between the global and sub-global analyses for biodiversity than for water provisioning, because the concepts and measures of biodiversity were more diverse in the sub-global assessments. [SG8]

The biophysical drivers of change mentioned most often across the sub-global assessments were land use change, climate change and variability, pollution, and invasive species. These drivers were seen, at best, as only partially under the control of the decision-maker at the particular scale of analysis. Land use change comprises a whole range of processes, including urbanization and urban growth (for example, São Paolo or Portugal), encroachment on natural ecosystems by agriculture (for example, Eastern Himalayas or Coastal British Columbia), and infrastructure development (for example, Tropical Forest Margins or the Caribbean Sea). A striking example of invasive species is in the Caribbean Sea, where dust blown from the Sahara across the Atlantic introduced new pathogenic bacteria that were at least partially responsible for coral reef diseases in the last two decades. [SG7]

Economic growth, structural change, and globalization were the most commonly identified indirect drivers. Their impacts on ecosystems are mediated by institutional and sociopolitical factors. Evidence from the sub-global assessments suggests that the impact of these indirect drivers depends on a range of institutional settings and on the structure of growth itself. The economic changes of the 1990s introduced a market system in the Altai-Sayan ecoregion in Russia and Mongolia. This resulted in higher cashmere producer prices, which in turn encouraged intensification of herding and the movement of herd locations closer to marketplaces, thus inducing overstocking in surrounding areas. On the other hand, in Trinidad, the liberalization of trade and the resulting competition forced down local prices of produce, which made local production of market crops uneconomical. The increase in transport triggered by global trade is seen as a major indirect driver for increases in species invasions. For example, the release of ballast water by ships coming from the Indo-Pacific region resulted in the introduction of the green mussel *Perna veridis* to Trinidad in the early 1990s. The mussel clogs up the intake pipes of industrial facilities in Trinidad, costing millions of dollars annually to remove. In a period of ten years, the mussel spread across the Caribbean all the way to Tampa Bay, Florida. However the mussel is also being harvested as a source of food in some parts of the Caribbean. [SG7]

Interactions among the drivers of ecosystem change in the sub-global assessments were seen to be of three major types: processes that trigger, reinforce, or constrain one another. The introduction of EU policies in Portugal *triggered* a high degree of dependency on decisions made at the European level, which in some cases may not be appropriate for local decision-making on ecosystems and their services. The Tropical Forest Margins assessment revealed that the resettlement projects designed to relieve pressures on the natural and social environment in the densely populated regions of coastal Southeast Asia have

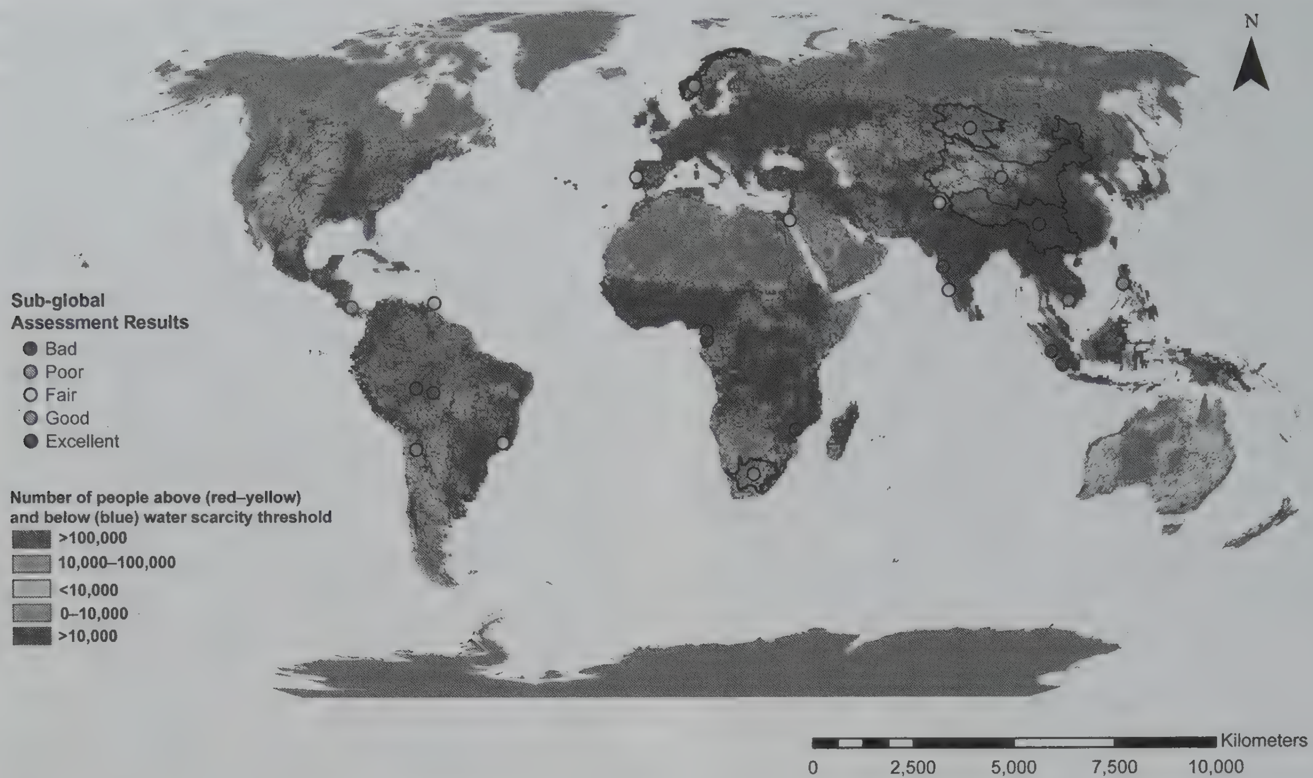

Figure SG3. Comparison between Freshwater Condition in the Sub-global Assessments and the Global Distribution of Human Population in 1995 Relative to a Threshold of Severe Water Scarcity. This map shows the distribution of the human population which faces severe water limitations (i.e., which is above the water scarcity threshold). The threshold corresponds to a ratio of 40% of water use or withdrawal to discharge (Vörösmarty et al. 2000). Boundaries of sub-global assessments that assess large areas are plotted in black.

reinforced processes of land use change, with swidden agriculture being the main driver in the processes of deforestation in the tropical forest margins. Cases where one driver is *constrained* by the action of another serve as a starting point for appropriate interventions. In the Stockholm Urban assessment in Sweden, for example, institutional change is a potentially effective intervention because it can constrain urban sprawl, a major driver of loss of green areas. [SG7]

Drivers of change act in very distinct ways in different regions. Though similar drivers were present in different assessments, their interactions, and thus the processes leading to ecosystem change, differed significantly from assessment to assessment. Though the three regions of the Amazon, Central Africa, and Southeast Asia in the Tropical Forest Margins assessment have the same set of individual drivers of deforestation, the processes of change in each region are distinct. Deforestation driven by swidden agriculture is more widespread in upland and foothill zones of Southeast Asia than in other regions. Road construction by the state followed by colonizing migrant settlers, who in turn practice slash-and-burn agriculture, is most frequent in lowland areas of Latin America, especially in the Amazon Basin. Pasture creation for cattle ranching is causing deforestation almost exclusively in the humid lowland regions of mainland South America. The spontaneous expansion of smallholder agriculture and fuelwood extraction for domestic uses are important causes of deforestation in Africa. While human-controlled drivers play a major role in determining the condition of ecosystem services, local biophysical constraints such as climate and soils also limit the production of ecosystem services. [SG7]

Drivers operate over different spatial and temporal scales, and the spatial and temporal scales of any given driver may be related in different ways. For a large number of drivers identified in the different sub-global assessments, drivers operating over large spatial areas tended to be associated with slower processes of change, while "small" processes tended to take place relatively rapidly. However, a significant number of exceptions to this pattern were observed. For example, the São Paulo assessment mentioned governance and legislation as a local, but slow driver. The same held for soil degradation as a biophysical driver in Viet Nam. On the other hand, in San Pedro de Atacama, Chile, the rapid change of technology in the mining sector taking place globally appeared as an important driver. This characteristic of technology—that is, fast change at the global, or at least national, scale—also held for the Argentine Pampas. [SG7]

> **Identifying effective response options that enhance human well-being and conserve ecosystem services requires consideration of drivers at different scales and involvement of actors at the appropriate scales.**

Understanding drivers, their interactions, and the consequences for ecosystem services and human

well-being is crucial to the design of effective responses. Although many responses target specific problems with ecosystem services, the nature of ecosystems means that such responses can have unintended consequences for multiple interacting drivers. Individual drivers may be difficult to influence without affecting others, and therefore response options targeted at interactions among drivers are often a more effective way to achieve a desired outcome, and may enable a more integrated and holistic approach to ecosystem service management. The adaptive co-management approach adopted by the Kristianstad Wetlands assessment in Sweden is an example; adaptive co-management systems are flexible, community-based systems of resource management tailored to specific places and situations, supported by, and working with, various organizations at different levels. Similarly, the river rehabilitation councils in the Laguna Lake Basin of the Philippines addressed a number of social and ecological drivers and engaged various stakeholders at different scales, resulting in several effective responses. [SG7, 9]

Scenario-building is an important method for involving stakeholders in policy formulation and for encouraging citizens to adopt their own policies aimed at environmental protection. The relevance, significance, and influence of the scenarios that are constructed will ultimately depend on who is involved in their development. Decision-makers may have difficulty introducing new policies designed to alter behaviors without the support of the general population. Participants in scenario-building can provide essential input on the relevance of storylines being developed and on the nature of uncertainties that are important at sub-global scales. [SG10]

Sub-global assessments used scenarios for multiple purposes, which often extended beyond the rationale for global scenarios. Besides being used by all of the sub-global assessments as a tool for decision-makers to plan for the future (as in the global scenarios), most sub-global assessments, such as SAfMA and the Northern Highlands Lake District of Wisconsin, also used scenarios as a means of communicating possible future changes and major uncertainties to stakeholders. In the San Pedro de Atacama, Chile, and the Bajo Chirripó, Costa Rica, assessments, for example, scenarios also proved to be an important tool for acquiring data about stakeholder preferences, perceptions, and values. In a few cases, including the Wisconsin, Caribbean Sea, and SAfMA assessments, scenarios had a role in defining the boundaries within which discussions about management and policy options relevant to ecosystem services and human well-being could be held. All of these examples also illustrate the use of participatory scenario development approaches in the sub-global assessments. [SG10]

Scenarios in the sub-global assessments differed markedly from the scenarios developed at the global level, although all were based on the same conceptual framework. The most significant differences were in terms of key uncertainties (which were much more context-specific at the local level), stakeholders involved, and the scales of analysis. Almost all sub-global scenarios identified institutional arrangements/governance as the key uncertainty, even with widely varying ecological and socioeconomic circumstances across the sub-global assessments. Many sub-global assessments sought to quantify the scenario storylines, but time constraints and the lack of available models prevented many from doing so, with the exception of the Western China and SAfMA Regional assessments. (See Figure SG4.) Nonetheless, substantive links were maintained with the global scenarios in the SAfMA, Caribbean Sea, and Portugal assessments, for example, through the use of global models in the development of regional scenarios. [SG10]

The effectiveness of a response is related to the degree of coherence among different types of policies and the degree of collaboration among stakeholders. Horizontal (multisector) collaboration ensures that multiple objectives (ecological, social, cultural, economic) are addressed in an integrated fashion. Vertical (multilevel) collaboration facilitates the generation of resources and increases the likelihood that responses have a positive impact on direct and indirect drivers of ecosystem change. Since these drivers typically occur at a continuum of social and ecological scales, responses would need to involve decision-makers (and actors) at multiple organizational levels. For instance, local responses such as coping and adapting to environmental change by the Bedouins in Egypt and by local communities in southern Africa have been largely ineffective due to the lack of institutional and financial support at the national level. In contrast, local people in the Eastern Himalayas took the initiative to form eco-development committees, and this became an effective response thanks to facilitative support from legislators. Collaboration is not only a local phenomenon; it has been initiated by all categories of actors operating at all identified organizational levels. [SG9]

Collaboration among actors is often facilitated by "bridging organizations." These provide arenas for multisector and/or multilevel collaboration for conceiving visions, trust-building, collaboration, learning, value formation, conflict resolution and other institutional innovations. Bridging organizations lower the transaction costs of collaboration and of crafting effective responses. They provide social incentives to identify possible win-win responses. The facilitation, leadership, and social incentives provided by bridging organizations or key persons in the community appear to be essential for capacity-building. For instance, in Kristianstad Wetlands, Sweden, a new organization called Ecomuseum has initiated a process based on collaboration, trust-building, and conflict resolution. Through voluntary participation within the existing legal framework, the ecosystem approach has been applied and an area with declining ecosystem services is now being transformed into a UNESCO Biosphere Reserve. In the Laguna Lake Basin of the Philippines, public agencies and nongovernmental organizations formed river rehabilitation councils that have been able to address social and ecological drivers in a collaborative and effective way. In San Pedro de Atacama, Chile, the assessment team provided the arena for collaborative learning, trust-building, visioning, and conflict resolution. These three examples illustrate the formation of bridging

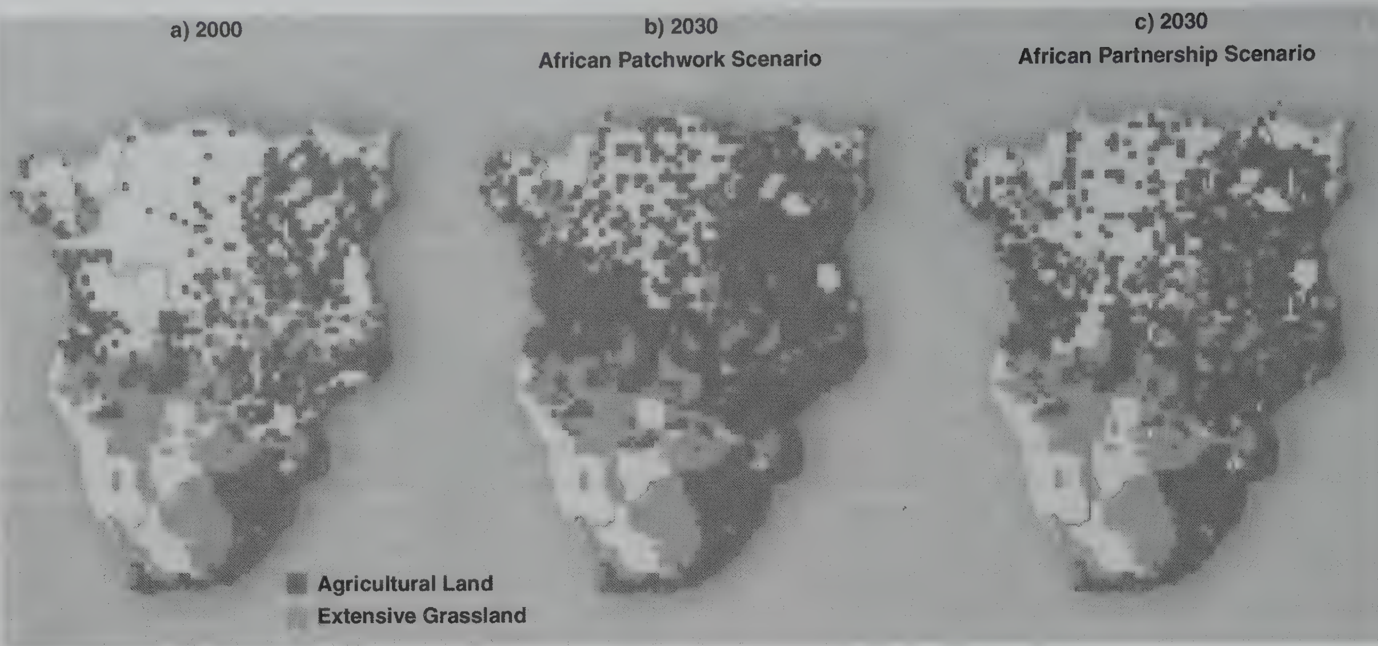

Figure SG4. Scenarios for Land Use Change in Southern Africa, 2000–2030. Under the Patchwork Scenario (low economic growth scenario), a greater area is converted to agriculture than under the Partnership Scenario (high economic growth). In both cases, the major changes occur north of the Zambezi river and are mainly due to increased livestock numbers rather than increased crop area. The model assumes that livestock are grazed extensively in the grassland areas and intensively on a portion of the area otherwise used for agriculture.

organizations that have resulted from bottom-up, top-down, and external initiatives, respectively. [SG9]

Declining ecosystem trends have been mitigated by innovative local responses. The "threats" observed at an aggregated, global level may be overestimated or underestimated from a sub-global perspective. Assessments at an aggregated level may fail to take into account the adaptive capacity of sub-global actors. Through collaboration in social networks, actors can develop new institutions and reorganize to mitigate declining conditions. On the other hand, in crafting their responses, sub-global actors tend to neglect drivers that are beyond their immediate influence. Hence, it is crucial for decision-makers to develop institutions at the global, regional, and national levels that strengthen the adaptive capacity of actors at the sub-national and local levels to develop context-specific responses that do address the full range of relevant drivers. The Biodiversity Management Committees in India are a good example of a national institution that enables local actors to respond to biodiversity loss. This means neither centralization nor decentralization but institutions at multiple levels that enhance the adaptive capacity and effectiveness of sub-national and local responses. [SG9]

When people with different interests, experiences, and knowledge cooperate, the potential diversity and effectiveness of response options is enhanced. Besides the democratic appeal of public participation, the knowledge base is broadened when local, traditional, and indigenous knowledge systems are acknowledged. By close monitoring of a diverse set of ecological variables, local stewards are often able to observe and understand early signals of ecosystem change, and distinguish this from natural variability. This is illustrated by Kristianstad Wetlands, Sweden, where local steward organizations observed declining bird populations and other signals that sparked the formation of a bridging organization. [SG9]

Local communities are not mere spectators, but active managers of the capacity of ecosystems to deliver services.

Ecosystems provide a sense of place and identity for local people, in addition to other ecosystem services. These intangible values, including aesthetic and recreational values, provide a rationale for management and precipitate management practices that enhance ecosystem resilience through caretaking and custodianship. In Vilcanota, Peru, spiritual values and belief systems, including the belief in Pacha Mama (Mother Earth) that encompasses the view that Earth is a living being, have allowed for the maintenance of a cultural identity among the Quechua peoples of the southern Peruvian Andes. In the Kristianstad Wetlands, Sweden, local farmers have once again begun to cultivate land previously abandoned, not primarily for economic gain, but more for the sense of place and identity that comes with the cultivation of this land. However, in many instances these values and belief systems have been eroded, leading to a shift in community-based management practices. For example, in San Pedro de Atacama, Chile, the erosion of the collective indigenous identity due to economic development has led to the sale of land to outsiders, and a consequent decline in agriculture and related traditional practices. [SG11]

Diversity in ecosystems and their services is important in reducing communities' vulnerability. Most

communities seek to maintain a diversity of livelihood options. This diversity buffers people against shocks and surprises such as climatic and economic fluctuations. In Papua New Guinea and India, for example, local farmers cultivate a wide variety of crops to avert the risk of crop failure. In Costa Rica, local communities create a mosaic landscape, consisting of sacred places, springs, agroecosystems, and high mountains. This results in a diversity of livelihood options at the local level. [SG11]

Local management systems are continuously evolving; some disappear while others are revived or newly invented. Many communities possess local, indigenous, or traditional knowledge about the interactions between humans and ecosystems. Local communities can affect ecosystem services and human well-being both positively and negatively. For example, in Xinjiang, western China, local people have elaborate traditional underground water harvesting structures ("karez") that maintain both water quality and quantity. Traditional community institutions that regulate access to the karez water exist, but in some cases are being weakened. In the Eastern Himalayas, India, economic incentives for private forest owners have led in some instances to deforestation in native forests. Nevertheless, the recognition of the role of communities as stewards of ecosystem services, and their empowerment, is essential to strengthen local capacity to manage ecosystems sustainably for human well-being. [SG11]

Communities are affected by larger-scale processes, but their ability to cope with and shape change varies. Decisions taken at higher scales often do not take into account the realities of local communities, resulting in negative impacts at the local level. Communities that cope successfully with these external forces have learned to adapt or even take advantage of them by creating horizontal links with other groups, forming alliances with powerful actors at "higher" spatial scales, and linking with national or global processes such as policy forums, markets, and multinational agreements. The Vilcanota assessment in Peru is driven by the indigenous communities there to meet their own needs, and the link to the global MA process has provided benefits to both these communities and the wider MA process. When conditions become impossible to adapt to, for example due to inflexible national policies, people are forced to migrate or face a reduced quality of life. In Sistelo, Portugal, for example, a government afforestation program on common property land (*baldio*) diminished the locally available livelihood and coping strategies by reducing land available for pastoralism, thereby accelerating the process of rural-urban migration. [SG11]

3. Why Conduct an Integrated Assessment at Multiple Scales?

The scale at which an assessment is undertaken significantly influences the problem definition and assessment results, as well as the solutions and responses selected.

A *comprehensive* multiscale assessment incorporates at least two nested-levels of complete, interacting assessments, each with a distinct user group, problem definition, and expert group. While the overall MA process was a multiscale assessment as defined here, the sub-global assessments ranged from comprehensive multiscale assessments to single scale assessments with explicit multiscale linkages or considerations. Only two sub-global assessments were conducted as *comprehensive* multiscale assessments with separate assessments at different scales (Southern Africa and Portugal). Other assessments, such as the Argentine Pampas, Coastal British Columbia, Colombia, and Western China, included significant *multiscale analyses* (for example, detailed case studies of particular sub-regions within the overall assessment) but were not *comprehensive* multiscale assessments since the case studies did not include their own user groups and problem definitions. All of the MA sub-global assessments examined processes that occur at multiple scales. [SG4]

The scale at which an assessment is undertaken significantly influences the problem definition and the assessment results. Findings of assessments conducted at different scales will differ due to differences in the questions posed and/or the information analyzed. Local communities are influenced by global, regional, and local factors. *Global* factors include commodity prices—for example, global trade asymmetries that influence local production patterns, as in Colombia (see Box SG5), Portugal, SAfMA Gariep, and Altai-Sayan—and global climate change. Examples of the latter include sea level rise (Papua New Guinea) and receding glaciers (Vilcanota, Peru, and Altai-Sayan). *Regional* factors include water supply regimes (for example, safe piped water in rural areas, as in SAfMA Gariep), regional climate (desertification as in Portugal), and geomorphological processes (soil erosion and degradation, as in Altai-Sayan and Trinidad). *Local* factors include market access (for example, distance to market, as in Papua New Guinea), disease prevalence (malaria, as in India Local and Papua New Guinea), or localized climate variability (patchy thunderstorms, as in SAfMA Gariep). Assessments conducted at different scales tend to focus on drivers and impacts most relevant at each scale, yielding different but

BOX SG5
Coffee and Forests in Colombia

The coffee-growing region of Colombia encompasses an area of more than 3.6 million hectares in the Andes, of which 870,000 hectares are currently devoted to coffee plantations. Coffee is grown in 605 municipalities in the country (56% of the national total), and involves 420,000 households and more than half a million agricultural productive units or farms. The old coffee plantations using varieties that were grown under shade trees were replaced with higher yield varieties that grow in open areas, leading to the loss of tree cover. The expansion of coffee production in other parts of the world (for example, Viet Nam) contributed to a reduction in international prices, resulting in a shift in agricultural production and changes in landscape use in the coffee-growing region of Colombia.

complementary findings. These provide some of the benefit of a multiscale assessment process, since each component assessment provides a different perspective on the issues addressed. [SG4]

A full multiscale assessment provides a powerful basis for evaluating the robustness and persistence of findings across scales. If an assessment of surface water availability finds that a specific region consistently experiences water scarcity across all the scales of analysis, the finding can be viewed with some degree of confidence. In contrast, if the same region is identified at one scale as water scarce, but is subsequently seen at another scale of analysis to exhibit varying degrees of scarcity and abundance, assessment teams are compelled to explore the possible reasons for such discrepancies. Inconsistency in findings across scales may stem from data or model inaccuracies or from local perceptions, needs, and/or requirements (for example, livelihood strategies at the local level that nullify broad-based patterns of access to subterranean water sources in areas that possess limited surface water). This full range of patterns emerged for different geographic areas in southern Africa analyzed by the regional, basin, and local scale assessments. [SG4]

Multiscale assessments offer insights and results that would otherwise be missed. The variability among sub-global assessments in problem definition, objectives, scale criteria, and systems of explanation increased at finer scales of assessment (for example, the visibility of social equity issues increased from coarser to finer scales of assessment). The role of biodiversity as a risk avoidance mechanism for local communities is frequently hidden until local assessments are conducted (examples include India Local; Sinai, Egypt; SAfMA Livelihoods). Processes of common concern emerging at all scales of assessment assumed different meanings and implications at different scales. For example, institutional responses at the global scale include formal global agreements and financial commitments, but at finer and finer sub-global scales, they increasingly involve relatively informal but effective efforts such as cooperative local resource management; examples include Caribbean Sea; India Local; Coastal British Columbia; Kristianstad Wetlands, Sweden. [SG4]

> **Using different knowledge systems provides insights that might otherwise be missed.**

Local and traditional ecological knowledge added significant insight about locally important resources and management practices, revealing information and understanding that is not reflected in the global assessment. This included names and uses of locally important plant species and practices to protect them (examples include India Local and Sinai), local drivers of change, specialized soil and water conservation practices, and coping strategies to protect human well-being. Local resource users also contributed valuable long-term perspectives about their social-ecological systems (Bajo Chirripó, Costa Rica), as well as information on key ecosystem processes that are important, uncertain, and difficult to control (Wisconsin). [SG5]

Practitioner knowledge—the diverse knowledge of multiple stakeholders—contributed more in terms of clarifying information needs and expectations, and less in terms of ecosystem management knowledge. Few assessments had significant analysis of the contribution of practitioner knowledge to the assessment. However, the Kristianstad Wetlands (Sweden) assessment was structured so that practitioner knowledge was fully integrated within the assessment process. The Tropical Forest Margins assessment showed that, in the areas studied, practitioner knowledge has become more integrated over time as there have been intensive efforts to ensure stakeholder participation. Several other assessments encountered problems in utilizing practitioner knowledge, in many cases because practitioners were viewed as users of the assessment results instead of knowledge holders in their own right. Engagement of assessment users and other practitioners as knowledge holders requires more attention to how knowledge is used in policy-making, decision-making, and NGO and bureaucratic practice. [SG5]

The extent to which local and traditional ecological knowledge contributed to the assessments varied, due to local circumstances, the predisposition and expertise of the assessment team, and the resources allocated to understanding and using local knowledge. Local and traditional knowledge is both complex and inherently contextual, and a rigorous and comprehensive investigation and interpretation of such knowledge is needed to fully understand it and the insights it provides on ecosystem dynamics. Collaborative relationships, such as those developed in Vilcanota and Bajo Chirripó, as well as participatory tools that broaden the level of inquiry, often result in the emergence of key issues of local importance. For example, in the Bajo Chirripó assessment, local participants found that there was existing traditional knowledge about natural resource management strategies, so the assessment emphasized learning more about and reviving these instead of introducing new ones. [SG5]

The MA assumed that participation would empower local resource users in two ways. First, it would increase local ownership over the assessment process and results. Second, validation by scientists would cause decision-makers to recognize and use local knowledge. However, as local participation varied from fully collaborative to extractive, so too did the potential for empowerment. At one end of the spectrum was the Vilcanota assessment, in which local resource users designed and directed the assessment process with relatively less involvement and direction from scientists. Western China was at the opposite end: what local knowledge was used was inserted into a scientific framework where local and traditional knowledge was not central. [SG5]

The sharing of knowledge across scales in the sub-global assessments did not occur to the extent hoped for by the MA. This was partially due to methodological issues, such as uneven emphasis on different knowledge sys-

tems and difficulties with the validation of different forms of knowledge. Procedures for the validation of local and traditional knowledge at the local level were adequately handled with the guidelines developed by the MA, but the sub-global assessments often lacked adequate processes of validation for the use of local knowledge at higher levels. Mediating institutions or boundary organizations are usually necessary for this, and these were not present for a number of the sub-global assessments. [SG5]

There is evidence that including multiple knowledge systems increases the relevance, credibility, and legitimacy of the assessment results for some users. For example, in Bajo Chirripó in Costa Rica, the involvement of non-scientists added legitimacy and relevance to assessment results for a number of potential assessment users at the local level. However, in many of the sub-global assessments, local resource users were only one among many groups of decision-makers, so the question of legitimacy needs to be taken together with that of empowerment. [SG5]

Some sub-global assessments confirmed that local institutions have a role in conferring greater power to local knowledge holders in cross-scale decision-making. For example, in India local and Kristianstad Wetlands (Sweden), deliberate efforts were made to embed the assessment within existing institutions that link local knowledge to higher-level decision-making processes. However, in the SAfMA Livelihoods assessment, local community institutions help to maintain knowledge, but by themselves were unable to ensure the use of local knowledge at higher-levels of decision-making. The Vilcanota and Bajo Chirripó assessments attempted to create space to begin a dialogue between local communities and decision-makers at higher scales. The success of these efforts can only be evaluated with more time. [SG5]

4. What Are the Important Lessons for Future Sub-global Assessments?

The MA conceptual framework served as a valuable tool and initial point of reference, but had to be adapted by some sub-global assessments.

Capturing the complex and dynamic nature of the interactions between ecosystems and humans required complementary conceptual frameworks in some contexts. Several community-based assessments adapted the MA framework to allow for more dynamic interplays between variables, capture fine-grained patterns and processes in complex systems, and leave room for a more spiritual worldview. In Peru and Costa Rica, for example, other conceptual frameworks were used that incorporated both the MA principles and local cosmologies. (See Figure SG5.) In southern Africa, various frameworks were used in parallel to offset the shortcomings of the MA framework for community assessments. These modifications and adaptations of the framework are an important outcome of the MA. [SG5, 11]

Capacity-building activities need to be an integral component of any assessment, but especially in a complex one such as the MA. Many sub-global assessments did not have the expertise to assess the various components of the MA conceptual framework, and there was a need to develop expertise through capacity-building activities. This included a need to develop methods to assess even the central tenet of the conceptual framework: the link between ecosystem services and human well-being. In addition to capacity-building activities initiated within assessments, the number and diversity of the assessments participating in the MA provided an ideal opportunity for capacity-building across the sub-global network. Networks formed among assessments became a way of exchanging experiences and methods and helped in the progress of some assessments. To fully incorporate multiple scales and knowledge systems in the design of all the sub-global assessments would have required more time and funding to develop the necessary tools and expertise. [SG6]

Multiscale assessments provide significant benefits, but they pose process and analytical challenges, are resource- and time-intensive, and, depending on assessment goals, may not always be necessary.

Both multiscale assessments and assessments incorporating multiscale analyses face analytical challenges not present in single-scale assessments. These challenges include: 1) the selection and measurement of ecosystem services and components of human well-being, and whether these should be consistent across scales; 2) determining the degree of nestedness; 3) establishing methods for cross-scale comparisons; and 4) ensuring information flow across the scales of the assessment. [SG4]

Multiscale assessments face additional challenges related to the most appropriate model for stakeholder involvement and participation. The presence of stakeholder groups from different scales, each with their own needs from the assessment and differing perceptions, can result in tension. Whereas a more rigid methodology and protocol may better meet analytical needs for multiscale analyses, a more flexible approach is often necessary to accommodate or adapt to different stakeholders from different scales. Thus design approaches for multiscale assessments vary depending on the requirements of analytical rigor and stakeholder involvement. [SG4]

Multiscale assessments are both resource- and time-intensive. These added costs may be justified when the goal is to inform and influence decisions, but a full multiscale assessment may not be necessary or desirable if the primary goal is only to formalize knowledge or to test the robustness of scientific findings. Sub-global assessments that were multiscale did obtain information benefits (improved assessment findings) related to the availability of more and better data, ground-truthing of data, and better analysis of the causes of change. However, many of these benefits could be as readily obtained (at lower cost) by

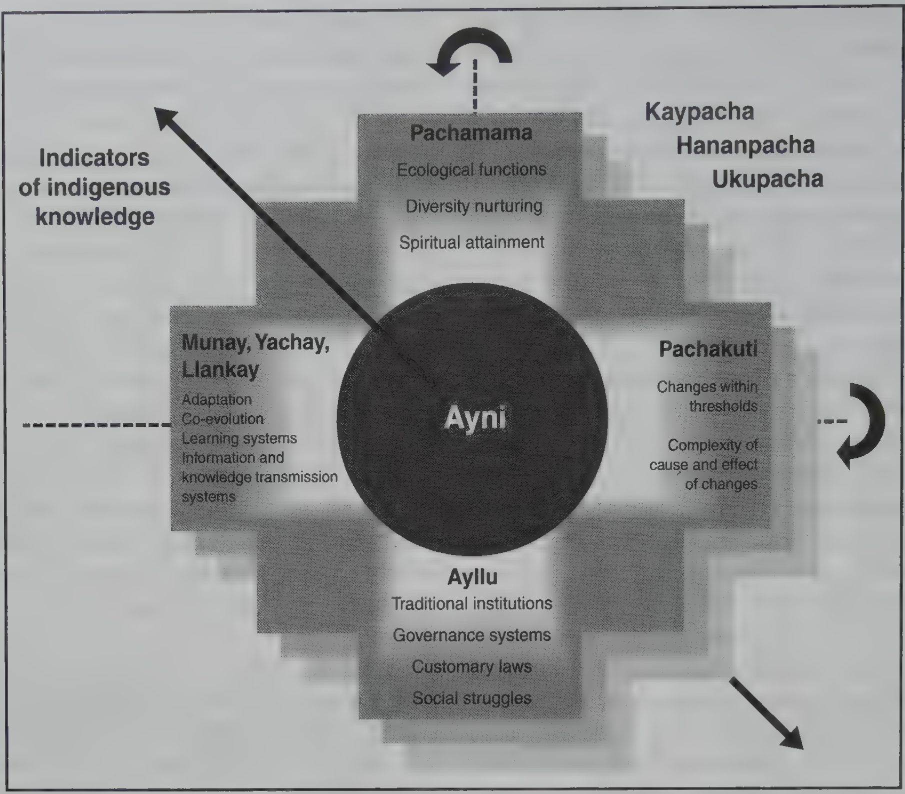

Figure SG5. Adapting the MA Conceptual Framework for Local Needs. The conceptual framework of the sub-global assessment in Vilcanota, Peru, was derived in part from the Inca cosmovision and in part from the MA conceptual framework, which was reinterpreted by the Quechua communities. The resulting framework has many similarities with the MA conceptual framework. The divergent features are considered to be highly important by the Quechua people conducting the assessment. Concepts such as reciprocity (*Ayni*), the inseparability of space and time, and the cyclical nature of all processes (*Pachakuti*) are important components of the Inca view of ecosystems. Love (*Munay*) and working (*Llankay*) bring humans to a higher state of knowledge *(Yachay)* about their surroundings, and are therefore key concepts linking Quechua communities to the natural world. *Ayllu* represents the governing institutions that regulate interactions among all living beings. *Kaypacha, Hananpacha,* and *Ukupacha* represent spatial scales and the cyclical relationship between the past, present, and future. Inherent in this concept of space and time is the adaptive capacity of the Quechua people, who welcome change and have become resilient to it. The Southern Cross shape of the Vilcanota conceptual framework diagram represents the *Chakana,* the most recognized and sacred shape to Quechua people. Chakana orders the world through deliberative and collective decision-making that emphasizes reciprocity (*Ayni*). *Pachamama* (the "mother earth," divinity, and place where past, present, and future coincide) is similar to the MA concept of ecosystem services combined with human well-being. Pachakuti is similar to the MA drivers (both direct and indirect). Ayllu (and Munay, Yachay, and Llankay) may be seen as responses, and are more organically integrated into the cyclic process of change and adaptation.

working fully at one or two scales while considering intermediate scales (multiscale analyses), rather than by conducting a full multiscale assessment. In contrast, a full multiscale design provided impact benefits associated with the use and adoption of the findings that could not be achieved through other approaches. The multiscale approach also increased the potential capacity of institutions and individuals involved to respond to changes in ecosystem services, even across existing political, national, and cultural boundaries (as in the case of SAfMA). [SG4]

For success, a sub-global assessment requires understanding of the context, adequate resources, champions and actively engaged users, and a governance structure able to manage competing needs.

The sub-global assessment process was dynamic and iterative. An assessment that links science with policy, such as the MA, provides a critical, objective evaluation and analysis of information, to meet user needs and support decision-making on complex issues. The three main stages of the assessment process were: an exploration stage, a design stage, and implementation of the resulting work plan, which included the review, validation, and communication of the findings. Throughout these stages, ongoing communication and user engagement permitted a flexible and iterative process, with some overlap between stages. (See Figure SG6.) [SG6]

Each sub-global assessment process was embedded in political, social, and environmental circumstances. The heterogeneity of these circumstances, as well as constraints such as the availability of information or particular expertise, necessitated a variety of approaches to using the MA conceptual framework. This reflects the reality of conducting integrated assessments at the sub-global level. An exploration of institutions that could potentially

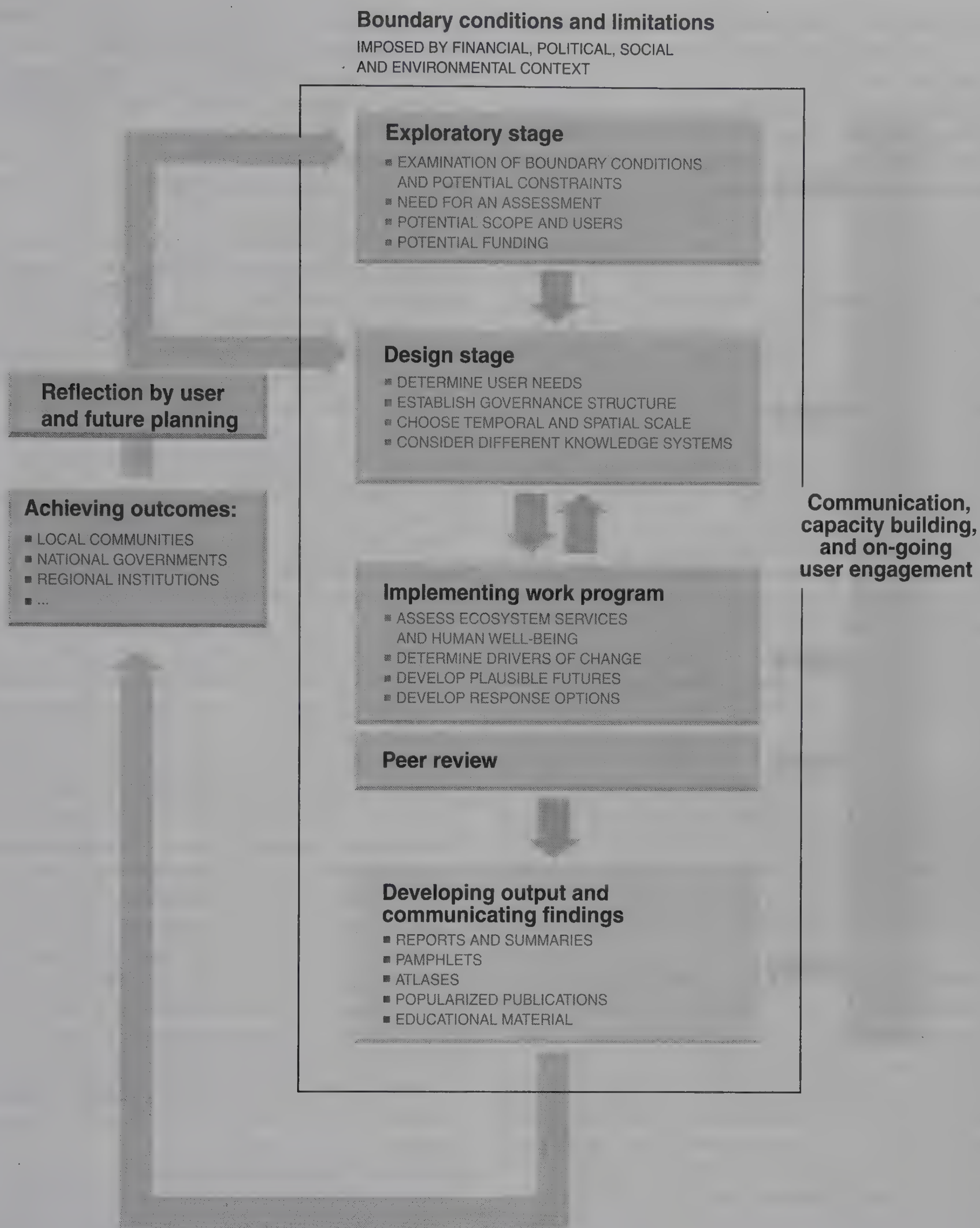

Figure SG6. The Sub-global Assessment Process

implement assessment outcomes should be included in the exploratory stages of the assessment. [SG6]

The sub-global assessments faced multiple constraints and had to overcome these challenges in order to make progress. Constraints included lack of data, limitations in financial support, and limited time. Further challenges included gaining the trust of different users, establishing and maintaining user engagement, securing technical leadership, and building the capacity to conduct multiscale, integrated assessments. These constraints limited the scope of the sub-global assessments in terms of the number of ecosystem services and aspects of human well-being that were included, the temporal and spatial scales considered, and the knowledge systems incorporated. Sub-global assessments that incorporated different knowledge systems required more time and resources to be set aside to support innovative work on these aspects. [SG6]

Assessments need champions. In many cases, specific individuals played key roles that were critical for providing the needed momentum and direction during different stages of an assessment. These roles include that of external facilitators who helped to establish the demand for an assessment,

and leadership to guide and sustain the assessment process. In some cases, small dedicated teams of people championed the assessment together. [SG6]

The groups that will use the assessment results must be involved throughout the entire assessment process, from the design of the assessment through to the communication of findings. Working with assessment users to identify processes that would use the assessment findings was essential, as it was an important part of establishing the demand for an assessment. The sub-global assessments responded to three broad categories of need for an assessment: (1) summary and synthesis of information on complex issues to support decision-making; (2) strengthening the capacity of the users to assess and manage their resources or to participate in resource management; (3) research to address gaps in knowledge for resource management. For the first two categories in particular, the assessments involved strong user engagement throughout the process. [SG6]

A governance structure that provided a forum for discussion was necessary in assessments that involved a wide range of users. Many sub-global assessments considered diverse user needs and needed to manage the tensions between them, as well as allocation of resources for competing needs. This included prioritizing the components of the MA conceptual framework to be addressed. [SG6]

> **The sub-global assessment process has generated new tools and methodologies and baseline information that have helped to empower stakeholders; more products and outcomes will come to fruition in the future.**

The sub-global assessments have yielded a number of tangible outcomes. Most global assessments, including the global component of the MA, have focused on producing synthetic reports, with their findings as the main outcome. In this regard, the final reports from individual sub-global assessments (or, for those assessments still in progress at the time this volume was written, peer-reviewed 30-page summaries) are a comparable result. Each of these assessments contains a wealth of information regarding the condition of ecosystem services, scenarios, and response options, each focused and shaped by the circumstances and needs of their particular setting. In addition, this volume aims to provide an overview of the sub-global process, with some comparisons and emerging patterns observed to date.

The sub-global assessment process has catalyzed the development of new tools and methodologies, the collation and generation of baseline information, and the creation of governance mechanisms that empower stakeholders. The constraints faced by the sub-global assessments sometimes led to innovative approaches to overcoming these constraints. Examples include the development of a novel biodiversity intactness index by the Southern Africa Regional assessment, and the training of technicians and video operators in the Peruvian Andes to lead and document the assessment of soil, water and agrobiodiversity by community groups. Another example was the advisory group of the San Pedro de Atacama assessment in Chile—which brought together different stakeholder groups to discuss ecosystem management for human well-being, for the first time. [SG12]

Some important results from the sub-global assessments are less tangible, and are primarily related to capacity-building. These include the capacities that were developed to lead and undertake similar, and improved, assessments in the future. These capacities will be reinforced by the network of institutions and professionals that has been developed in the course of the MA. One example was the development of a fellowship program for younger scientists, many of whom went on to work closely with the Coordinating Lead Authors of this assessment volume.

The value added by sub-global assessment processes in the future can be increased. In doing so, the following tradeoffs should be taken into consideration:

- a rigorous approach to selecting assessments will ensure better geographical coverage and representation of ecosystems, but this should be weighed against the benefits of more innovation, diversity and strong user demand that arise from a bottom-up selection process;
- fully nested, multiscale assessments will deliver significant information and impact benefits, but may not always be necessary, especially in the light of the substantial resources and capacity required to undertake them; and
- focusing on a small set of services in common across all sub-global assessments will facilitate greater comparability, but the diverse circumstances and priorities of individual assessments may necessitate flexibility and a less rigidly uniform analytical approach.

A number of important additional considerations for future sub-global assessments would include:

- ensuring the availability of essential training and capacity-building, and tools and methodologies, especially in areas like developing scenarios and multiscale approaches to assessment;
- fostering continued interdisciplinary approaches involving both natural and social scientists, to comprehensively analyze the links between ecosystem services and human well-being; and
- sufficient funding for the full set of assessment activities planned.

Some of the most important results of the sub-global assessment process are yet to come. The existing sub-global assessments are at very different stages of implementation, ranging from completed assessment to those in their early stages. It is important to build on the experience gained so far and to continue the existing network. This will also enable a better assessment of the real impact of the process on the management of ecosystems for human well-being. [SG12]

Glossary

Abatement cost: See *Marginal abatement cost.*

Abundance: The total number of individuals of a taxon or taxa in an area, population, or community. Relative abundance refers to the total number of individuals of one taxon compared with the total number of individuals of all other taxa in an area, volume, or community.

Active adaptive management: See *Adaptive management.*

Adaptation: Adjustment in natural or human systems to a new or changing environment. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive capacity: The general ability of institutions, systems, and individuals to adjust to potential damage, to take advantage of opportunities, or to cope with the consequences.

Adaptive management: A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. In active adaptive management, management is treated as a deliberate experiment for purposes of learning.

Afforestation: Planting of forests on land that has historically not contained forests. (Compare *Reforestation.*)

Agrobiodiversity: The diversity of plants, insects, and soil biota found in cultivated systems.

Agroforestry systems: Mixed systems of crops and trees providing wood, non-wood forest products, food, fuel, fodder, and shelter.

Albedo: A measure of the degree to which a surface or object reflects solar radiation.

Alien species: Species introduced outside its normal distribution.

Alien invasive species: See *Invasive alien species.*

Aquaculture: Breeding and rearing of fish, shellfish, or plants in ponds, enclosures, or other forms of confinement in fresh or marine waters for the direct harvest of the product.

Benefits transfer approach: Economic valuation approach in which estimates obtained (by whatever method) in one context are used to estimate values in a different context.

Binding constraints: Political, social, economic, institutional, or ecological factors that rule out a particular response.

Biodiversity (a contraction of biological diversity): The variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. Biodiversity includes diversity within species, between species, and between ecosystems.

Biodiversity regulation: The regulation of ecosystem processes and services by the different components of biodiversity.

Biogeographic realm: A large spatial region, within which ecosystems share a broadly similar biota. Eight terrestrial biogeographic realms are typically recognized, corresponding roughly to continents (e.g., Afrotropical realm).

Biological diversity: See *Biodiversity.*

Biomass: The mass of tissues in living organisms in a population, ecosystem, or spatial unit.

Biome: The largest unit of ecological classification that is convenient to recognize below the entire globe. Terrestrial biomes are typically based on dominant vegetation structure (e.g., forest, grassland). Ecosystems within a biome function in a broadly similar way, although they may have very different species composition. For example, all forests share certain properties regarding nutrient cycling, disturbance, and biomass that are different from the properties of grasslands. Marine biomes are typically based on biogeochemical properties. The WWF biome classification is used in the MA.

Bioprospecting: The exploration of biodiversity for genetic and biochemical resources of social or commercial value.

Biotechnology: Any technological application that uses biological systems, living organisms, or derivatives thereof to make or modify products or processes for specific use.

Biotic homogenization: Process by which the differences between biotic communities in different areas are on average reduced.

Blueprint approaches: Approaches that are designed to be applicable in a wider set of circumstances and that are not context-specific or sensitive to local conditions.

Boundary organizations: Public or private organizations that synthesize and translate scientific research and explore its policy implications to help bridge the gap between science and decision-making.

Bridging organizations: Organizations that facilitate, and offer an arena for, stakeholder collaboration, trust-building, and conflict resolution.

Capability: The combinations of doings and beings from which people can choose to lead the kind of life they value. Basic capability is the capability to meet a basic need.

Capacity building: A process of strengthening or developing human resources, institutions, organizations, or networks. Also referred to as capacity development or capacity enhancement.

Capital value (of an ecosystem): The present value of the stream of ecosystem services that an ecosystem will generate under a particular management or institutional regime.

Capture fisheries: See *Fishery.*

Carbon sequestration: The process of increasing the carbon content of a reservoir other than the atmosphere.

Cascading interaction: See *Trophic cascade.*

Catch: The number or weight of all fish caught by fishing operations, whether the fish are landed or not.

Coastal system: Systems containing terrestrial areas dominated by ocean influences of tides and marine aerosols, plus nearshore marine areas. The inland extent of coastal ecosystems is the line where land-based influences dominate, up to a maximum of 100 kilometers from the coastline or 100-meter elevation (whichever is closer to the sea), and the outward extent is the 50-meter-depth contour. See also *System.*

Collaborative (or joint) forest management: Community-based management of forests, where resource tenure by local communities is secured.

Common pool resource: A valued natural or human-made resource or facility in which one person's use subtracts from another's use and where it is often necessary but difficult to exclude potential users from the resource. (Compare *Common property resource.*)

Common property management system: The institutions (i.e., sets of rules) that define and regulate the use rights for common pool resources. Not the same as an open access system.

Common property resource: A good or service shared by a well-defined community. (Compare *Common pool resource.*)

Community (ecological): An assemblage of species occurring in the same space or time, often linked by biotic interactions such as competition or predation.

Community (human, local): A collection of human beings who have something in common. A local community is a fairly small group of people who share a common place of residence and a set of institutions based on this fact, but the word 'community' is also used to refer to larger collections of people who have something else in common (e.g., national community, donor community).

Condition of an ecosystem: The capacity of an ecosystem to yield services, relative to its potential capacity.

Condition of an ecosystem service: The capacity of an ecosystem service to yield benefits to people, relative to its potential capacity.

Constituents of well-being: The experiential aspects of well-being, such as health, happiness, and freedom to be and do, and, more broadly, basic liberties.

Consumptive use: The reduction in the quantity or quality of a good available for other users due to consumption.

Contingent valuation: Economic valuation technique based on a survey of how much respondents would be willing to pay for specified benefits.

Core dataset: Data sets designated to have wide potential application throughout the Millennium Ecosystem Assessment process. They include land use, land cover, climate, and population data sets.

Cost-benefit analysis: A technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits.

Cost-effectiveness analysis: Analysis to identify the least cost option that meets a particular goal.

Critically endangered species: Species that face an extremely high risk of extinction in the wild. See also *Threatened species.*

Cross-scale feedback: A process in which effects of some action are transmitted from a smaller spatial extent to a larger one, or vice versa. For example, a global policy may constrain the flexibility of a local region to use certain response options to environmental change, or a local agricultural pest outbreak may affect regional food supply.

Cultivar (a contraction of cultivated variety): A variety of a plant developed from a natural species and maintained under cultivation.

Cultivated system: Areas of landscape or seascape actively managed for the production of food, feed, fiber, or biofuels.

Cultural landscape: See *Landscape.*

Cultural services: The nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values.

Decision analytical framework: A coherent set of concepts and procedures aimed at synthesizing available information to help policymakers assess consequences of various decision options. DAFs organize the relevant information in a suitable framework, apply decision criteria (both based on some paradigms or theories), and thus identify options that are better than others under the assumptions characterizing the analytical framework and the application at hand.

Decision-maker: A person whose decisions, and the actions that follow from them, can influence a condition, process, or issue under consideration.

Decomposition: The ecological process carried out primarily by microbes that leads to a transformation of dead organic matter into inorganic mater.

Deforestation: Conversion of forest to non-forest.

Degradation of an ecosystem service: For *provisioning services,* decreased production of the service through changes in area over which the services is provided, or decreased production per unit area. For *regulating* and *supporting services,* a reduction in the benefits obtained from the service, either through a change in the service or through human pressures on the service exceeding its limits. For *cultural services,* a change in the ecosystem features that decreases the cultural benefits provided by the ecosystem.

Degradation of ecosystems: A persistent reduction in the capacity to provide ecosystem services.

Desertification: land degradation in drylands resulting from various factors, including climatic variations and human activities.

Determinants of well-being: Inputs into the production of well-being, such as food, clothing, potable water, and access to knowledge and information.

Direct use value (of ecosystems): The benefits derived from the services provided by an ecosystem that are used directly by an economic agent. These include consumptive uses (e.g., harvesting goods) and nonconsumptive uses (e.g., enjoyment of scenic beauty). Agents are often physically present in an ecosystem to receive direct use value. (Compare *Indirect use value.*)

Disability-adjusted life years: The sum of years of life lost due to premature death and illness, taking into account the age of death compared with natural life expectancy and the number of years of life lived with a disability. The measure of number of years lived with the disability considers the duration of the disease, weighted by a measure of the severity of the disease.

Diversity: The variety and relative abundance of different entities in a sample.

Driver: Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

Driver, direct: A driver that unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy. (Compare *Driver, indirect.*)

Driver, endogenous: A driver whose magnitude can be influenced by the decision-maker. Whether a driver is exogenous or endogenous depends on the organizational scale. Some drivers (e.g., prices) are exogenous to a decision-maker at one level (a farmer) but endogenous at other levels (the nation-state). (Compare *Driver, exogenous.*)

Driver, exogenous: A driver that cannot be altered by the decision-maker. (Compare *Driver, endogenous.*)

Driver, indirect: A driver that operates by altering the level or rate of change of one or more direct drivers. (Compare *Driver, direct.*)

Drylands: See *Dryland system.*

Dryland system: Areas characterized by lack of water, which constrains the two major interlinked services of the system: primary production and nutrient cycling. Four dryland subtypes are widely recognized: dry sub-humid, semiarid, arid, and hyperarid, showing an increasing level of aridity or moisture deficit. See also *System.*

Ecological character: See *Ecosystem properties.*

Ecological degradation: See *Degradation of ecosystems.*

Ecological footprint: An index of the area of productive land and aquatic ecosystems required to produce the resources used and to assimilate the wastes produced by a defined population at a specified material standard of living, wherever on Earth that land may be located.

Ecological security: A condition of ecological safety that ensures access to a sustainable flow of provisioning, regulating, and cultural services needed by local communities to meet their basic capabilities.

Ecological surprises: unexpected—and often disproportionately large—consequence of changes in the abiotic (e.g., climate, disturbance) or biotic (e.g., invasions, pathogens) environment.

Ecosystem: A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit.

Ecosystem approach: A strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use. An ecosystem approach is based on the application of appropriate scientific methods focused on levels of biological organization, which encompass the essential structure, processes, functions, and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

Ecosystem assessment: A social process through which the findings of science concerning the causes of ecosystem change, their consequences for human well-being, and management and policy options are brought to bear on the needs of decision-makers.

Ecosystem boundary: The spatial delimitation of an ecosystem, typically based on discontinuities in the distribution of organisms, the biophysical environment (soil types, drainage basins, depth in a

water body), and spatial interactions (home ranges, migration patterns, fluxes of matter).

Ecosystem change: Any variation in the state, outputs, or structure of an ecosystem.

Ecosystem function: See *Ecosystem process.*

Ecosystem interactions: Exchanges of materials, energy, and information within and among ecosystems.

Ecosystem management: An approach to maintaining or restoring the composition, structure, function, and delivery of services of natural and modified ecosystems for the goal of achieving sustainability. It is based on an adaptive, collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic, and institutional perspectives, applied within a geographic framework, and defined primarily by natural ecological boundaries.

Ecosystem process: An intrinsic ecosystem characteristic whereby an ecosystem maintains its integrity. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem properties: The size, biodiversity, stability, degree of organization, internal exchanges of materials, energy, and information among different pools, and other properties that characterize an ecosystem. Includes ecosystem functions and processes.

Ecosystem resilience: See *Resilience.*

Ecosystem resistance: See *Resistance.*

Ecosystem robustness: See *Ecosystem stability.*

Ecosystem services: The benefits people obtain from ecosystems. These include *provisioning services* such as food and water; *regulating services* such as flood and disease control; *cultural services* such as spiritual, recreational, and cultural benefits; and *supporting services* such as nutrient cycling that maintain the conditions for life on Earth. The concept "ecosystem goods and services" is synonymous with ecosystem services.

Ecosystem stability (or ecosystem robustness): A description of the dynamic properties of an ecosystem. An ecosystem is considered stable or robust if it returns to its original state after a perturbation, exhibits low temporal variability, or does not change dramatically in the face of a perturbation.

Elasticity: A measure of responsiveness of one variable to a change in another, usually defined in terms of percentage change. For example, own-price elasticity of demand is the percentage change in the quantity demanded of a good for a 1% change in the price of that good. Other common elasticity measures include supply and income elasticity.

Emergent disease: Diseases that have recently increased in incidence, impact, or geographic range; that are caused by pathogens that have recently evolved; that are newly discovered; or that have recently changed their clinical presentation.

Emergent property: A phenomenon that is not evident in the constituent parts of a system but that appears when they interact in the system as a whole.

Enabling conditions: Critical preconditions for success of responses, including political, institutional, social, economic, and ecological factors.

Endangered species: Species that face a very high risk of extinction in the wild. See also *Threatened species.*

Endemic (in ecology): A species or higher taxonomic unit found only within a specific area.

Endemic (in health): The constant presence of a disease or infectious agent within a given geographic area or population group; may also refer to the usual prevalence of a given disease within such area or group.

Endemism: The fraction of species that is endemic relative to the total number of species found in a specific area.

Epistemology: The theory of knowledge, or a "way of knowing."

Equity: Fairness of rights, distribution, and access. Depending on context, this can refer to resources, services, or power.

Eutrophication: The increase in additions of nutrients to freshwater or marine systems, which leads to increases in plant growth and often to undesirable changes in ecosystem structure and function.

Evapotranspiration: See *Transpiration.*

Existence value: The value that individuals place on knowing that a resource exists, even if they never use that resource (also sometimes known as conservation value or passive use value).

Exotic species: See *Alien species.*

Externality: A consequence of an action that affects someone other than the agent undertaking that action and for which the agent is neither compensated nor penalized through the markets. Externalities can be positive or negative.

Feedback: See *Negative feedback, Positive feedback,* and *Cross-scale feedback.*

Fishery: A particular kind of fishing activity, e.g., a trawl fishery, or a particular species targeted, e.g., a cod fishery or salmon fishery.

Fish stock: See *Stock.*

Fixed nitrogen: See *Reactive nitrogen.*

Flyway: Areas of the world used by migratory birds in moving between breeding and wintering grounds.

Forest systems: Systems in which trees are the predominant life forms. Statistics reported in this assessment are based on areas that are dominated by trees (perennial woody plants taller than five meters at maturity), where the tree crown cover exceeds 10%, and where the area is more than 0.5 hectares. "Open forests" have a canopy cover between 10% and 40%, and "closed forests" a canopy cover of more than 40%. "Fragmented forests" refer to mosaics of forest patches and non-forest land. See also *System.*

Freedom: The range of options a person has in deciding the kind of life to lead.

Functional diversity: The value, range, and relative abundance of traits present in the organisms in an ecological community.

Functional redundancy (= functional compensation): A characteristic of ecosystems in which more than one species in the system can carry out a particular process. Redundancy may be total or partial—that is, a species may not be able to completely replace the other species or it may compensate only some of the processes in which the other species are involved.

Functional types (= functional groups = guilds): Groups of organisms that respond to the environment or affect ecosystem processes in a similar way. Examples of plant functional types include nitrogen-fixer versus non-fixer, stress-tolerant versus ruderal versus competitor, resprouter versus seeder, deciduous versus evergreen. Examples of animal functional types include granivorous versus fleshy-fruit eater, nocturnal versus diurnal predator, browser versus grazer.

Geographic information system: A computerized system organizing data sets through a geographical referencing of all data included in its collections.

Globalization: The increasing integration of economies and societies around the world, particularly through trade and financial flows, and the transfer of culture and technology.

Global scale: The geographical realm encompassing all of Earth.

Governance: The process of regulating human behavior in accordance with shared objectives. The term includes both governmental and nongovernmental mechanisms.

Health, human: A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity. The health of a whole community or population is reflected in measurements of disease incidence and prevalence, age-specific death rates, and life expectancy.

High seas: The area outside of national jurisdiction, i.e., beyond each nation's Exclusive Economic Zone or other territorial waters.

Human well-being: See *Well-being.*

Income poverty: See *Poverty.*

Indicator: Information based on measured data used to represent a particular attribute, characteristic, or property of a system.

Indigenous knowledge (or local knowledge): The knowledge that is unique to a given culture or society.

Indirect interaction: Those interactions among species in which a species, through direct interaction with another species or modification of resources, alters the abundance of a third species with which it is not directly interacting. Indirect interactions can be trophic or nontrophic in nature.

Indirect use value: The benefits derived from the goods and services provided by an ecosystem that are used indirectly by an economic agent. For example, an agent at some distance from an ecosystem may derive benefits from drinking water that has been purified as it passed through the ecosystem. (Compare *Direct use value.*)

Infant mortality rate: Number of deaths of infants aged 0–12 months divided by the number of live births.

Inland water systems: Permanent water bodies other than salt-water systems on the coast, seas and oceans. Includes rivers, lakes, reservoirs wetlands and inland saline lakes and marshes. See also *System.*

Institutions: The rules that guide how people within societies live, work, and interact with each other. Formal institutions are written or codified rules. Examples of formal institutions would be the constitution, the judiciary laws, the organized market, and property rights. Informal institutions are rules governed by social and behavioral norms of the society, family, or community. Also referred to as organizations.

Integrated coastal zone management: Approaches that integrate economic, social, and ecological perspectives for the management of coastal resources and areas.

Integrated conservation and development projects: Initiatives that aim to link biodiversity conservation and development.

Integrated pest management: Any practices that attempt to capitalize on natural processes that reduce pest abundance. Sometimes used to refer to monitoring programs where farmers apply pesticides to improve economic efficiency (reducing application rates and improving profitability).

Integrated responses: Responses that address degradation of ecosystem services across a number of systems simultaneously or that also explicitly include objectives to enhance human well-being.

Integrated river basin management: Integration of water planning and management with environmental, social, and economic development concerns, with an explicit objective of improving human welfare.

Interventions: See *Responses.*

Intrinsic value: The value of someone or something in and for itself, irrespective of its utility for people.

Invasibility: Intrinsic susceptibility of an ecosystem to be invaded by an alien species.

Invasive alien species: An alien species whose establishment and spread modifies ecosystems, habitats, or species.

Irreversibility: The quality of being impossible or difficult to return to, or to restore to, a former condition. See also *Option value, Precautionary principle, Resilience,* and *Threshold.*

Island systems: Lands isolated by surrounding water, with a high proportion of coast to hinterland. The degree of isolation from the mainland in both natural and social aspects is accounted by the *isola effect.* See also *System.*

Isola effect: Environmental issues that are unique to island systems. This uniqueness takes into account the physical seclusion of islands as isolated pieces of land exposed to marine or climatic disturbances with a more limited access to space, products, and services when compared with most continental areas, but also includes subjective issues such as the perceptions and attitudes of islanders themselves.

Keystone species: A species whose impact on the community is disproportionately large relative to its abundance. Effects can be produced by consumption (trophic interactions), competition, mutualism, dispersal, pollination, disease, or habitat modification (nontrophic interactions).

Land cover: The physical coverage of land, usually expressed in terms of vegetation cover or lack of it. Related to, but not synonymous with, *land use.*

Landscape: An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems. The term cultural landscape is often used when referring to landscapes containing significant human populations or in which there has been significant human influence on the land.

Landscape unit: A portion of relatively homogenous land cover within the local-to-regional landscape.

Land use: The human use of a piece of land for a certain purpose (such as irrigated agriculture or recreation). Influenced by, but not synonymous with, *land cover.*

Length of growing period: The total number of days in a year during which rainfall exceeds one half of potential evapotranspiration. For boreal and temperate zone, growing season is usually defined as a number of days with the average daily temperature that exceeds a definite threshold, such as 10° Celsius.

Local knowledge: See *Indigenous knowledge.*

Mainstreaming: Incorporating a specific concern, e.g. sustainable use of ecosystems, into policies and actions.

Malnutrition: A state of bad nourishment. Malnutrition refers both to undernutrition and overnutrition, as well as to conditions arising from dietary imbalances leading to diet-related noncommunicable diseases.

Marginal abatement cost: The cost of abating an incremental unit of, for instance, a pollutant.

Marine system: Marine waters from the low-water mark to the high seas that support marine capture fisheries, as well as deepwater (>50 meters) habitats. Four sub-divisions (marine biomes) are recognized: the coastal boundary zone; trade-winds; westerlies; and polar.

Market-based instruments: Mechanisms that create a market for ecosystem services in order to improving the efficiency in the way the service is used. The term is used for mechanisms that create new markets, but also for responses such as taxes, subsidies, or regulations that affect existing markets.

Market failure: The inability of a market to capture the correct values of ecosystem services.

Mitigation: An anthropogenic intervention to reduce negative or unsustainable uses of ecosystems or to enhance sustainable practices.

Mountain system: High-altitude (greater than 2,500 meters) areas and steep mid-altitude (1,000 meters at the equator, decreasing to sea level where alpine life zones meet polar life zones at high latitudes) areas, excluding large plateaus.

Negative feedback: Feedback that has a net effect of dampening perturbation.

Net primary productivity: See *Production, biological.*

Non-linearity: A relationship or process in which a small change in the value of a driver (i.e., an independent variable) produces an disproportionate change in the outcome (i.e., the dependent variable). Relationships where there is a sudden discontinuity or change in rate are sometimes referred to as abrupt and often form the basis of thresholds. In loose terms, they may lead to unexpected outcomes or "surprises."

Nutrient cycling: The processes by which elements are extracted from their mineral, aquatic, or atmospheric sources or recycled from their organic forms, converting them to the ionic form in which biotic uptake occurs and ultimately returning them to the atmosphere, water, or soil.

Nutrients: The approximately 20 chemical elements known to be essential for the growth of living organisms, including nitrogen, sulfur, phosphorus, and carbon.

Open access resource: A good or service over which no property rights are recognized.

Opportunity cost: The benefits forgone by undertaking one activity instead of another.

Option value: The value of preserving the option to use services in the future either by oneself (option value) or by others or heirs (bequest value). Quasi-option value represents the value of avoiding irreversible decisions until new information reveals whether certain ecosystem services have values society is not currently aware of.

Organic farming: Crop and livestock production systems that do not make use of synthetic fertilizers, pesticides, or herbicides. May also include restrictions on the use of transgenic crops (genetically modified organisms).

Pastoralism, pastoral system: The use of domestic animals as a primary means for obtaining resources from habitats.

Perturbation: An imposed movement of a system away from its current state.

Polar system: Treeless lands at high latitudes. Includes Arctic and Antarctic areas, where the polar system merges with the northern boreal forest and the Southern Ocean respectively. See also *System.*

Policy failure: A situation in which government policies create inefficiencies in the use of goods and services.

Policy-maker: A person with power to influence or determine policies and practices at an international, national, regional, or local level.

Pollination: A process in the sexual phase of reproduction in some plants caused by the transportation of pollen. In the context of ecosystem services, pollination generally refers to animal-assisted pollination, such as that done by bees, rather than wind pollination.

Population, biological: A group of individuals of the same species, occupying a defined area, and usually isolated to some degree from other similar groups. Populations can be relatively reproductively isolated and adapted to local environments.

Population, human: A collection of living people in a given area. (Compare *Community (human, local).*)

Positive feedback: Feedback that has a net effect of amplifying perturbation.

Poverty: The pronounced deprivation of well-being. Income poverty refers to a particular formulation expressed solely in terms of per capita or household income.

Precautionary principle: The management concept stating that in cases "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation," as defined in the Rio Declaration.

Prediction (or forecast): The result of an attempt to produce a most likely description or estimate of the actual evolution of a variable or system in the future. See also *Projection* and *Scenario.*

Primary production: See *Production, biological.*

Private costs and benefits: Costs and benefits directly felt by individual economic agents or groups as seen from their perspective. (Externalities imposed on others are ignored.) Costs and benefits are valued at the prices actually paid or received by the group, even if these prices are highly distorted. Sometimes termed "financial" costs and benefits. (Compare *Social costs and benefits.*)

Probability distribution: A distribution that shows all the values that a random variable can take and the likelihood that each will occur.

Production, biological: Rate of biomass produced by an ecosystem, generally expressed as biomass produced per unit of time per unit of surface or volume. Net primary productivity is defined as the energy fixed by plants minus their respiration.

Production, economic: Output of a system.

Productivity, biological: See *Production, biological.*

Productivity, economic: Capacity of a system to produce high levels of output or responsiveness of the output of a system to inputs.

Projection: A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from "predictions" in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized; they are therefore subject to substantial uncertainty.

Property rights: The right to specific uses, perhaps including exchange in a market, of ecosystems and their services.

Provisioning services: The products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water.

Public good: A good or service in which the benefit received by any one party does not diminish the availability of the benefits to others, and where access to the good cannot be restricted.

Reactive nitrogen (or fixed nitrogen): The forms of nitrogen that are generally available to organisms, such as ammonia, nitrate, and organic nitrogen. Nitrogen gas (or dinitrogen), which is the major component of the atmosphere, is inert to most organisms.

Realm: Used to describe the three major types of ecosystems on earth: terrestrial, freshwater, and marine. Differs fundamentally from *biogeographic realm.*

Reforestation: Planting of forests on lands that have previously contained forest but have since been converted to some other use. (Compare *Afforestation.*)

Regime shift: A rapid reorganization of an ecosystem from one relatively stable state to another.

Regulating services: The benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases.

Relative abundance: See *Abundance.*

Reporting unit: The spatial or temporal unit at which assessment or analysis findings are reported. In an assessment, these units are chosen to maximize policy relevance or relevance to the public and thus may differ from those upon which the analyses were conducted (e.g., analyses conducted on mapped ecosystems can be reported on administrative units). See also *System.*

Resilience: The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage, and respond to these dynamics.

Resistance: The capacity of an ecosystem to withstand the impacts of drivers without displacement from its present state.

Responses: Human actions, including policies, strategies, and interventions, to address specific issues, needs, opportunities, or problems. In the context of ecosystem management, responses may be of legal, technical, institutional, economic, and behavioral nature and may operate at various spatial and time scales.

Riparian: Something related to, living on, or located at the banks of a watercourse, usually a river or stream.

Safe minimum standard: A decision analytical framework in which the benefits of ecosystem services are assumed to be incalculable and should be preserved unless the costs of doing so rise to an intolerable level, thus shifting the burden of proof to those who would convert them.

Salinization: The buildup of salts in soils.

Scale: The measurable dimensions of phenomena or observations. Expressed in physical units, such as meters, years, population size, or quantities moved or exchanged. In observation, scale determines the relative fineness and coarseness of different detail and the selectivity among patterns these data may form.

Scenario: A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships. Scenarios are neither predictions nor projections and sometimes may be based on a "narrative storyline." Scenarios may include projections but are often based on additional information from other sources.

Security: Access to resources, safety, and the ability to live in a predictable and controllable environment.

Service: See *Ecosystem services.*

Social costs and benefits: Costs and benefits as seen from the perspective of society as a whole. These differ from private costs and benefits in being more inclusive (all costs and benefits borne by some member of society are taken into account) and in being valued at social opportunity cost rather than market prices, where these differ. Sometimes termed "economic" costs and benefits. (Compare *Private costs and benefits.*)

Social incentives: Measures that lower transaction costs by facilitating trust-building and learning as well as rewarding collaboration and conflict resolution. Social incentives are often provided by bridging organizations.

Socioecological system: An ecosystem, the management of this ecosystem by actors and organizations, and the rules, social norms, and conventions underlying this management. (Compare *System.*)

Soft law: Non-legally binding instruments, such as guidelines, standards, criteria, codes of practice, resolutions, and principles or declarations, that states establish to implement national laws.

Soil fertility: The potential of the soil to supply nutrient elements in the quantity, form, and proportion required to support optimum plant growth. See also *Nutrients.*

Speciation: The formation of new species.

Species: An interbreeding group of organisms that is reproductively isolated from all other organisms, although there are many partial exceptions to this rule in particular taxa. Operationally, the term *species* is a generally agreed fundamental taxonomic unit, based on morphological or genetic similarity, that once described and accepted is associated with a unique scientific name.

Species diversity: Biodiversity at the species level, often combining aspects of species richness, their relative abundance, and their dissimilarity.

Species richness: The number of species within a given sample, community, or area.

Statistical variation: Variability in data due to error in measurement, error in sampling, or variation in the measured quantity itself.

Stock (in fisheries): The population or biomass of a fishery resource. Such stocks are usually identified by their location. They can be, but are not always, genetically discrete from other stocks.

Stoichiometry, ecological: The relatively constant proportions of the different nutrients in plant or animal biomass that set constraints on production. Nutrients only available in lower proportions are likely to limit growth.

Storyline: A narrative description of a scenario, which highlights its main features and the relationships between the scenario's driving forces and its main features.

Strategies: See *Responses.*

Streamflow: The quantity of water flowing in a watercourse.

Subsidiarity, principle of: The notion of devolving decision-making authority to the lowest appropriate level.

Subsidy: Transfer of resources to an entity, which either reduces the operating costs or increases the revenues of such entity for the purpose of achieving some objective.

Subsistence: An activity in which the output is mostly for the use of the individual person doing it, or their family, and which is a significant component of their livelihood.

Subspecies: A population that is distinct from, and partially reproductively isolated from, other populations of a species but that has not yet diverged sufficiently that interbreeding is impossible.

Supporting services: Ecosystem services that are necessary for the production of all other ecosystem services. Some examples include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.

Sustainability: A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs.

Sustainable use (of an ecosystem): Human use of an ecosystem so that it may yield a continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

Symbiosis: Close and usually obligatory relationship between two organisms of different species, not necessarily to their mutual benefit.

Synergy: When the combined effect of several forces operating is greater than the sum of the separate effects of the forces.

System: In the Millennium Ecosystem Assessment, reporting units that are ecosystem-based but at a level of aggregation far higher than that usually applied to ecosystems. Thus the system includes many component ecosystems, some of which may not strongly interact with each other, that may be spatially separate, or that may be of a different type to the ecosystems that constitute the majority, or matrix, of the system overall. The system includes the social and economic systems that have an impact on and are affected by the ecosystems included within it. For example, the Condition and Trend Working Group refers to "forest systems," "cultivated systems," "mountain systems," and so on. Systems thus defined are not mutually exclusive, and are permitted to overlap spatially or conceptually. For instance, the "cultivated system" may include areas of "dryland system" and vice versa.

Taxon (pl. taxa): The named classification unit to which individuals or sets of species are assigned. Higher taxa are those above the species level. For example, the common mouse, *Mus musculus,* belongs to the Genus *Mus,* the Family Muridae, and the Class Mammalia.

Taxonomy: A system of nested categories (*taxa*) reflecting evolutionary relationships or morphological similarity.

Tenure: See *Property rights,* although also sometimes used more specifically in reference to the temporal dimensions and security of property rights.

Threatened species: Species that face a high (*vulnerable species*), very high (*endangered species*), or extremely high (*critically endangered species*) risk of extinction in the wild.

Threshold: A point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels. For example, species diversity of a landscape may decline steadily with increasing habitat degradation to a certain point, then fall sharply after a critical threshold of degradation is reached. Human behavior, especially at group levels, sometimes exhibits threshold effects. Thresholds at which irreversible changes occur are especially of concern to decision-makers. (Compare *Non-linearity.*)

Time series data: A set of data that expresses a particular variable measured over time.

Total economic value framework: A widely used framework to disaggregate the components of utilitarian value, including *direct use value, indirect use value, option value,* quasi-option value, and *existence value.*

Total factor productivity: A measure of the aggregate increase in efficiency of use of inputs. TFP is the ratio of the quantity of output divided by an index of the amount of inputs used. A common input index uses as weights the share of the input in the total cost of production.

Total fertility rate: The number of children a woman would give birth to if through her lifetime she experienced the set of age-specific fertility rates currently observed. Since age-specific rates generally change over time, TFR does not in general give the actual number of births a woman alive today can be expected to have. Rather, it is a synthetic index meant to measure age-specific birth rates in a given year.

Trade-off: Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems.

Traditional ecological knowledge: The cumulative body of knowledge, practices, and beliefs evolved by adaptive processes and handed down through generations. TEK may or may not be indigenous or local, but it is distinguished by the way in which it is acquired and used, through the social process of learning and sharing knowledge. (Compare *Indigenous knowledge.*)

Traditional knowledge: See *Traditional ecological knowledge.*

Traditional use: Exploitation of natural resources by indigenous users or by nonindigenous residents using traditional methods. Local use refers to exploitation by local residents.

Transpiration: The process by which water is drawn through plants and returned to the air as water vapor. Evapotranspiration is combined loss of water to the atmosphere via the processes of evaporation and transpiration.

Travel cost methods: Economic valuation techniques that use observed costs to travel to a destination to derive demand functions for that destination.

Trend: A pattern of change over time, over and above short-term fluctuations.

Trophic cascade: A chain reaction of top-down interactions across multiple tropic levels. These occur when changes in the presence or absence (or shifts in abundance) of a top predator alter the production at several lower trophic levels. Such positive indirect effects of top predators on lower tropic levels are mediated by the consumption of mid-level consumers (generally herbivores).

Trophic level: The average level of an organism within a food web, with plants having a trophic level of 1, herbivores 2, first-order carnivores 3, and so on.

Umbrella species: Species that have either large habitat needs or other requirements whose conservation results in many other species being conserved at the ecosystem or landscape level.

Uncertainty: An expression of the degree to which a future condition (e.g., of an ecosystem) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined terminology or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Urbanization: An increase in the proportion of the population living in urban areas.

Urban systems: Built environments with a high human population density. Operationally defined as human settlements with a minimum population density commonly in the range of 400 to 1,000 persons per square kilometer, minimum size of typically between 1,000 and 5,000 people, and maximum agricultural employment usually in the vicinity of 50–75%. See also *System.*

Utility: In economics, the measure of the degree of satisfaction or happiness of a person.

Valuation: The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) usually in terms of something that can be counted, often money, but also through methods and measures from other disciplines (sociology, ecology, and so on). See also *Value.*

Value: The contribution of an action or object to user-specified goals, objectives, or conditions. (Compare *Valuation.*)

Value systems: Norms and precepts that guide human judgment and action.

Voluntary measures: Measures that are adopted by firms or other actors in the absence of government mandates.

Vulnerability: Exposure to contingencies and stress, and the difficulty in coping with them. Three major dimensions of vulnerability are involved: exposure to stresses, perturbations, and shocks; the sensitivity of people, places, ecosystems, and species to the stress or perturbation, including their capacity to anticipate and cope with the stress; and the resilience of the exposed people, places, ecosystems, and species in terms of their capacity to absorb shocks and perturbations while maintaining function.

Vulnerable species: Species that face a high risk of extinction in the wild. See also *Threatened species.*

Water scarcity: A water supply that limits food production, human health, and economic development. Severe scarcity is taken to be equivalent to 1,000 cubic meters per year per person or greater than 40% use relative to supply.

Watershed (also catchment basin): The land area that drains into a particular watercourse or body of water. Sometimes used to describe the dividing line of high ground between two catchment basins.

Water stress: See *Water scarcity.*

Well-being: A context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, good social relations, security, peace of mind, and spiritual experience.

Wetlands: Areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. May incorporate riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six meters at low tide laying within the wetlands.

Wise use (of an ecosystem): Sustainable utilization for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem

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Launched in June 2001 and involving more than 1,300 leading scientists from 95 nations, the Millennium Ecosystem Assessment (MA) is a ground-breaking study of how humans have altered ecosystems, how changes in ecosystem services affect human well-being, both now and in the future, and what options exist to enhance human well-being while conserving ecosystems. Integrating findings at the local, regional, and global scales and including insights from alternative intellectual traditions, the Millennium Ecosystem Assessment offers the first truly comprehensive picture of the health of the planet.

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—*Kofi Annan, Secretary-General of the United Nations*

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CBD CMS GEF ICSU International Council for Science IUCN The World Conservation Union Ramsar CONVENTION ON WETLANDS (Ramsar, Iran, 1971)

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